# COSMOS.

London
Wilson and Ogilvy, 57, Skinner Street,
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# COSMOS:

## SKETCH

OF A

## PHYSICAL DESCRIPTION OF THE UNIVERSE.

BY

## ALEXANDER VON HUMBOLDT.

VOL. III.

*Naturæ vero rerum vis atque majestas in omnibus momentis fide caret, si quis modo partes ejus ac non totam complectatur animo.*—PLIN. H. N. lib. vii. c. 1.

TRANSLATED UNDER THE SUPERINTENDENCE OF

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# SUMMARY OF THE CONTENTS.



Retrospective glance on what has been presented in the preceding volumes. Nature considered under a twofold point of view,—in the pure objectivity of external phænomena,—and as reflected internally in the minds of men. A significant arrangement of the order in which phænomena are presented leads of itself to a view of their causal connection. Completeness in the enumeration of particulars is not aimed at, and least of all in the description of the reflex image of nature under the influence of the creative power of the imagination. By the side of the actual external world there arises an ideal inner world, full of physical symbolical myths, differing in different races and climates, but of which the traces continue for centuries, and often disturb the clear view of Nature in long subsequent generations. Original impossibility of completeness in the recognition of cosmical phænomena. Discovery of empirical laws, and search after causal connection between phænomena. Description of the Universe, and Explanation of the Universe. How in the present existing, we may discern traces of past processes of formatiou. Different phases of the explanation of the natural world, and attempts at understanding the order of Nature. Oldest fundamental mode of contemplation of the Hellenic national mind: physiological phantasies of the Ionic school; germs of a scientific contemplation of Nature. Two directions in which explanations of Nature were sought: by the assumption of different material principles (elements), and by processes of rarefaction and condensation.

## MORE DETAILED ANALYSIS OF THE DIFFERENT SECTIONS OF THE ASTRONOMICAL PORTION OF THE COSMOS.

### α. Astrognosy.

### β. Solar Domain.

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## *ERRATA.*

| Page | line |
|---|---|
| 8 ... | 2, from bottom, for "third and last volume," read "third and fourth volumes." |
| 44 ... | 12, from top, for "Aristillus," read "Aristyllus." |
| 72 ... | 5, from bott. for "at 14′ 7″," read "first 14′ 7″, then 11′." |
| 74 ... | 17, from top, for "167976," read "167612." |
| 203 ... | 8, for "ε Lyræ," read "ε 5 Lyræ." |
| 212 ... | 6, after "earliest calculations," insert "and measurements." |
| 266 ... | 6, after "1851" close the parenthesis. |
| 348 ... | 3, after "Laplace," insert (556). |
| 363 ... | 5, from bottom, after "earth," insert (586). |
| 370 ... | 23, from top, for "(603) read "(602)." |
| ii. ... | 10, from bottom, for "105," read "108." (The reference to the English edition is correct.) |
| xiii. ... | 11, for "393,'" read "392." (The reference to the English edition is correct.) |
| lxv. ... | 5, from top, for "593," read "540." |

# COSMOS.

# COSMOS:

## A PHYSICAL DESCRIPTION OF THE UNIVERSE.

### SPECIAL RESULTS OF OBSERVATION IN THE DOMAIN OF COSMICAL PHÆNOMENA.

#### INTRODUCTION.

In pursuance of the aim which I had proposed to myself, as attainable in a degree commensurate with my own powers and with the present state of knowledge, I have considered Nature, in the two volumes of the Cosmos which have already appeared, in a twofold point of view. I have sought to represent her, first, in the pure objectivity of external phænomena, and, next, as the reflex of the image received through the senses on the mirror of man's inner being, his ideas and feelings.

The external world of phænomena has been described under the scientific form of a general picture of Nature in her two great spheres, uranologic and telluric; beginning with the stars which glimmer amidst nebulæ in the most distant regions of space, and descending through our plane-

tary system to the vegetable covering with which the earth is invested, and to the minutest organisms often floating in the air, which escape our unassisted vision. In order to allow us to contemplate with greater clearness the existence of a common bond comprehending the whole of the material universe, the government of never changing laws, and the causal connection of entire groups of phænomena so far as is yet known to us, it was necessary to avoid the accumulation of detached facts. Such care appeared more particularly requisite where, in the telluric sphere of the Cosmos, by the side of the dynamic actions of moving forces, we find manifested the powerful influence of the specific heterogeneity of matter. In the sidereal or uranological part of the Cosmos, the problems, in all that can be reached by observation, are in their nature of admirable simplicity; being by the theory of motion susceptible of rigid calculation, according to the attracting force of matter and the quantity of its mass. If, as I believe, we are justified in regarding the aerolites, or meteoric asteroids, as parts of our planetary system, they, but they only, by falling upon our globe, enable us to recognise diversity of substance in bodies belonging to cosmical space external to our own planet. (1) We have here the reason why terrestrial phænomena have hitherto been less generally, and less successfully, subjected to mathematical development and treatment, than have the movements of the heavenly bodies, with their mutual perturbations and periodical returns, governed, so far as our perceptions extend, only by the one fundamental force of homogeneous matter.

My endeavours in the telluric portion of the description of Nature were directed to the arrangement of the phæno-

mena in significant order, suggestive of their causal connection. The terrestrial globe was described in its form, its mean density, the gradations of its temperature increasing with increasing depth, its electro-magnetic currents and evolution of polar light. On the reaction of the interior of the planet upon its external crust depend all the phænomena of volcanic activity; comprising those of earthquakes in more or less complete circles of waves, as well as their simply dynamic effects, eruptions of gas, hot springs, and mud. The most powerful manifestation of internal terrestrial activity is the elevation of fire-emitting mountains. We have described volcanoes, both central and forming chains, not only as destructive agents, but also as producing or emitting various substances, and still forming under our eyes, for the most part periodically, those classes of rock which we term eruptive rocks; while, in contrast with this formation, we have also shewn the precipitation, likewise still going on, of sedimentary rocks from fluids containing their minute constituent particles in solution or suspension. Such a comparison of that which is still in process of elaboration, with those strata of the crust of the globe which have long since been solidified, conducts to the distinction of geological epochs, and to a secure determination of the successive age of formations, in which lie enveloped, in successive series chronologically recognisable, the remains of extinct races of plants and animals, forming the Floras and Faunas of an earlier world. The modes of formation, alteration, and upheaving of the strata, varying at different geological epochs, are conditions on which all the particular features of the surface of the globe depend: on them depend the distribution of land and water, and the configuration and

extent of the continental masses in the vertical as well as in the horizontal direction. These features of the earth's surface constitute, in their turn, conditions on which depend the thermic state of oceanic currents, the meteorological processes of the aerial covering of our planet, and the geographical and typical distribution and extension of animal and vegetable forms. This brief allusion to the order and manner in which the various telluric phænomena are presented, in the view or picture of Nature in the first volume of my work, is, I think, sufficient to shew that the mere bringing together of great and apparently complicated results of observation, may promote insight into their causal connection. On the other hand, the interpretation of Nature is obscured when the description languishes under too great an accumulation of insulated facts.

If, in a carefully designed objective representation of the world of phænomena, completeness in the enumeration of particulars ought not to be desired, neither should it be sought for in the description of the reflex of external nature on the human mind. Here it was needful to draw the limits still closer. The measureless domain of human thought, fertilised for thousands of years by the impulses and powers of mental activity, presents in different races, and at different stages of civilisation, at one time a cheerful, and at another a melancholy, aspect; (2) a delicate appreciation of the beautiful in nature, or a dull insensibility to all that she can display. At an early period we see the human mind directed to the deification of natural forces or powers, and of certain objects of the material universe; at a later period it followed religious impulses of a higher and more purely spiritual character. (3) The internal reflex of external

phænomena influences in a variety of ways the mysterious process of the formation of language, (4) a process in which original physical temperament, and the impressions received from surrounding nature, both act as powerful concurrent elements. Man elaborates within himself the rough materials supplied through the senses; and the results or products of such mental processes belong as essentially to the domain of the Cosmos, as do the external phænomena which are reflected in the internal mirror of the mind.

As the image of nature reflected under the influence of excited creative imagination cannot be preserved pure and true, there arises, by the side of what we call the actual or external world, an ideal or internal world, filled with fantastic and partly symbolical myths, and animated by creatures of fabulous shape, whose different parts are borrowed either from various animals of the present creation, or even from the remains of extinct species. (5) Marvellous and fabulous flowers and trees spring from the mythical soil, as in the songs of the Edda, the giant ash, the world-tree, Ygdrasil, whose branches rise above the heavens, while one of its triple roots reaches down to the raging fountains of the lower world. (6) Thus the cloud-land of physical myths is filled, according to the particular character of the race and climate, either with pleasing images or shapes of terror, and these enter into the circles of ideas of later generations, to whom they are bequeathed.

If my published work does not correspond sufficiently to the title, of which I have often acknowledged the imprudent boldness, the reproach of incompleteness must especially attach to that portion which touches on the spiritual life in the Cosmos, or the reflex image of external nature in the

domain of human thought and feeling. In this part of my undertaking I have more particularly contented myself with dwelling on the subjects which lay most in the direction of my previously long-cherished studies: on the manifestations of the more or less vivid feeling of nature in classical antiquity, and in modern times;—on the fragments of poetic description of nature, whose tone of colouring has been so materially influenced by individuality of national character, and by the religious monotheistic view of creation;—on the pleasing magic of landscape painting;—and on the history of the physical contemplation of the Universe; *i. e.* the history of the gradual development, in the course of two thousand years, of the recognition of the unity of phænomena, and of the Universe as a Whole.

In a work so comprehensive, and at once scientific and literary in its aim, all that a first and imperfect attempt can aspire to accomplish is, to influence rather by what it may call forth than by what it can itself supply. A book of Nature, which may be worthy of so exalted a title, can only be looked for when the natural sciences, notwithstanding their inherent incapability of absolute completion, shall yet, by continued progress and extension, have reached a higher standing point; and when thus a new and clearer light shall have been thrown alike on the two spheres of the one Cosmos,—the external world perceived by the senses, and its internal reflection in the mind.

I think I have sufficiently indicated the reasons which have determined me not to give to the general picture of Nature a wider extension. It remains for the third and last volume of my work to supply some of the deficiencies of the earlier ones, and to put forward those results of

observation which form the principal basis of present scientific opinion. The order of succession in which these results are presented will again be that which, in conformity with previously enounced principles, was followed by me in the general view of Nature. Before, however, proceeding to particular results in the several sciences, I desire still to add a few more general elucidatory considerations. The unexpected favour with which my undertaking has been received, both in my own and in other countries, makes me doubly feel the need of expressing myself once more as distinctly as possible in reference to the fundamental idea of the entire work; and respecting requirements which I have never even attempted to fulfil, because, according to my individual view of our experimental knowledge, their fulfilment could not be contemplated by me. With these considerations, to which I am led by the desire of justifying my manner of proceeding, there are naturally associated historical reminiscences of earlier attempts to discover the idea of the Universe, which should so comprehend its structure as to reduce all phænomena, in their causal connection, to a single principle.

The fundamental principle (7) of my work on the Cosmos, as developed by me more than twenty years ago in lectures delivered in the French and German languages, at Paris and at Berlin, consists in the constant tendency or endeavour to embrace the phænomena of the universe as a natural Whole; to shew how, in particular groups of the phænomena, those conditions which are common to the entire group,—*i. e.* the government of great and comprehensive laws,—have been discovered and recognised, and by what means we ascend from the knowledge of these laws to that of their

causal connection. Such a tendency to advance continually towards the comprehension of the plan of the Universe, or the order of Nature, commences with the combination and generalisation of particular facts;—with the recognition of the conditions under which phænomena, *i. e.* the manifestations of physical alterations, are always reproduced in a similar manner: it conducts to the thoughtful consideration of the materials supplied by observation and experiment; but it does not conduct to a "view of the Universe derived from speculation and the development of thought alone, or to a science or doctrine of the unity of Nature apart from experience." We are, I here repeat it, still far from the time, when it may be thought possible to concentrate all the perceptions of our senses into the unity of one comprehensive idea embracing the whole of Nature. The safe path was perceived a full century before Francis Bacon, by Leonardo da Vinci, and indicated by him in a few words:—"Comminciare dall' esperienza, e per mezzo di questa, scoprirne la ragione." (8) In many groups of phænomena we must, indeed, still content ourselves with a deduction of empirical laws; but the highest object of all investigation into nature, though seldom attained, is the discovery of physical causes. (9) This is most satisfactorily and conclusively accomplished, when it is possible to connect the laws of phænomena with the causes which explain them, by the intervention of mathematical reasoning. It is, however, only in some particularly favoured parts of natural science that the "physical description" coincides with the "physical explanation of the universe." The two expressions cannot yet be regarded as identical. The inherent grandeur and solemnity of that

mental labour, the boundaries of which are hereby marked, consist in the elevating consciousness of the infinite nature of the object of its efforts,—the comprehension of the unknown and inexhaustible fulness of creation, whether formed or in process of formation, whether existing or to be hereafter developed.

Such efforts, acting throughout all ages, must have led often, and under many various forms, to the illusory hope of having attained the goal, and found the principle by which all that is variable in the material universe, the totality of all the phænomena which are cognizable by the senses, might be explained. After a long period in which, in conformity with the early fundamental mode of contemplation of the Hellenic national mind, the forming, transforming, and destroying forces of nature had been honoured as divine or spiritual powers, clothed in human forms, ([10]) there became developed amidst the physiological fancies of the Ionic school the germ of a scientific contemplation of Nature. The first cause of all phænomena was explained in two different directions ([11]), sometimes according to mechanical, and sometimes according to dynamic views,—from the assumption of concrete corporeal principles called "elements of nature," or from processes of rarefaction and condensation. The hypothesis, primarily perhaps of Indian origin, of four or five substantially different elements, has continued, from the didactic poem of Empedocles to the most recent times, to mingle itself with all systems of natural philosophy, forming an evidence and monument of high antiquity of man's desire to seek for the generalisation and simplification of ideas, not only in forces, but also in the qualitative essences of substances.

In the later development of the Ionic physiology, Anax-

agoras of Clazomene passed from the assumption of material forces to the idea of a Spirit, distinct from all matter but intermixed with all its homogeneous ultimate particles. He spoke of the world-regulating Mind (νοῦς) governing the continually progressive formation of the Universe, and being the original cause of all motion, and thus of all physical phænomena. It is by the assumption of a centrifugal revolving movement (12), by whose intermission, previously noticed, he accounts for the fall of meteoric stones, that Anaxagoras explains the apparent motion of the celestial sphere from East to West. This hypothesis indicates the commencement of vortex-theories, which more than two thousand years afterwards became of much cosmical importance by the writings of Descartes, Huygens, and Hooke. This work is not the place in which to enquire whether Anaxagoras means by the "world-regulating Mind" the Godhead itself, or whether he only means to speak pantheistically of a spiritual principle in the general life of Nature. (13)

In marked contrast with the two divisions of the Ionic School, though likewise embracing the whole Universe, is the mathematical symbolism of the Pythagoreans. In the phænomena of the Universe, their regards were fixed exclusively on the dominion of law in the determination of form (the five fundamental forms); and on the ideas of number, measure, harmony, and antithesis. To them, *things* were mirrored in *numbers*, which are as it were an "imitative representation" (μίμησις) thereof. They saw in the illimitability of numbers, inasmuch as they can be endlessly repeated and increased, the character of eternity, and of the infinitude of Nature. They considered that the

essence of things may be known by ratios of numbers, and their alterations and transformations by combinations of numbers. Plato's Physics also contain attempts to reduce all the essences of substances in the universe, and their gradations of changes, to corporeal forms; and these to the simplest (triangular) plane figures. (14) But what the ultimate principles (as it were the elements of the elements), may be, "this," said Plato, with modest diffidence, "is known to God alone, and to whomso is beloved by Him among men." This mathematical treatment of physical phænomena, the formation of atomic doctrines, the philosophy of measure and of harmony, have continued to a late period to influence the development of the natural sciences: they have also contributed to lead fanciful discoverers astray from the true road, into by-paths which it may be requisite to notice in the history of the physical contemplation of the Universe. "There dwells a peculiar and fascinating charm recognised by all antiquity in the simple relations of time and space as manifested in tones, numbers, and lines." (15)

The idea of the order and government of the Universe shines forth pure and exalted in the writings of Aristotle. All the phænomena of Nature are described in the "Auscultationes Physicæ" as moving vital activities of a Universal Power. On the "unmoved Motor of the World depend Heaven and Nature," (16)—Nature being the terrestrial sphere of phænomena. The "Orderer," and the final cause of all alterations which can be perceived, must be regarded as imperceptible to sense, as distinct from all matter. (17) Unity in the different manifestations of force in substances is raised by Aristotle to the rank of a leading principle, and these manifestations of force are themselves always reduced to

motions. Thus we even find in the book "De Anima" ([18]) the germ of the undulatory theory of light. The sensation of seeing follows from a movement or vibration of the medium between the sight and the object seen, not from effluxes either from the object or from the eye. Hearing is compared with seeing, as sound is also a consequence of concussion of the air.

In inculcating the exercise of thoughtful reason in the search after that which is general or universal amidst the particular facts perceived by the senses, Aristotle always comprehends the whole of Nature, and the internal connection not only of forces but also of organic forms. In the book which treats of the parts (organs,) of animals, he clearly enounces his belief in the gradual chain of beings ascending from lower to higher forms. Nature proceeds in uninterrupted progressive development from the inanimate (elementary,) through plants to animals: advancing first to "what indeed is not properly an animal, but so nearly allied thereto that it is on the whole but little distinguished from one." ([19]) In the transition of forms "the intermediate steps are almost insensible." ([20]) The unity of Nature is to the Stagirite the great problem of the Cosmos. He says, with singular vivacity of expression, "In Nature nothing is isolated; there is no want of connection as in a bad tragedy." ([21])

In all the physical writings of this profound, sage, and accurate observer of nature, we cannot fail to recognise the philosophical tendency to subordinate all the phænomena of the one Cosmos to a single principle of explanation; but the defective state of knowledge, and ignorance of the method of experimenting, (*i. e.*, of calling forth phænomena under definite conditions), prevented even small

groups of physical processes from being comprehended in their causal connection. All was reduced to ever recurring antitheses of cold and heat, moisture and drought, primitive density and rarity; and even to the effecting of alterations in the material world by means of a kind of internal antagonism (antiperistasis), which reminds us of our present hypotheses of opposite polarities and the contrasts of + and —. (22) Aristotle's supposed solutions of problems do but reproduce the facts themselves in disguise; and in explaining meteorological and optical processes, his elsewhere ever powerful and concise style often passes into self complacent diffuseness or Hellenic verbal redundancy. As the mind of Aristotle was but little directed to diversity of substances, but chiefly to the consideration of motion, we see the fundamenal idea of ascribing all telluric natural phænomena to the impulse of the motion of the heavens, (*i. e.* the revolution of the celestial sphere), recurring continually, always indicated and cherished with special partiality, but not presented with definiteness or precision. (23) The impulse here spoken of imports only the communication of motion as the ground of all terrestrial phænomena. Pantheistic views are excluded: the Godhead is the highest "presiding Unity, regulating all things, revealing Himself in all spheres of the entire Universe, giving to each creature its destination, and holding all together by His absolute power." (24) The ideas of purpose and adaptation are not so much applied to the subordinate processes of nature, (those of inorganic elementary nature), as by preference to the higher organisations (25) of the animal and vegetable worlds. It is remarkably striking that in the teaching of Aristotle, as if he had been aware of the distribution of masses and the

existence of perturbations, the Deity employs a number of astral Spirits to maintain the planets in their eternal appointed courses. ([26]) The stars display the image of the Divinity in the visible world. The small pseudo-Aristotelian book of the Cosmos, which is certainly of Stoic origin, is not mentioned here, notwithstanding its name. It presents, it is true, in a descriptive manner, and often with animated rhetoric and vivacity of colouring, both the heavens and the earth, and the currents of the ocean and of the atmosphere; but it manifests no tendency to reduce the phænomena of the Cosmos to general physical principles, *i. e.*, to principles founded in the properties of matter.

I have dwelt the longer on the most brilliant epoch of antiquity, as respects views of Nature, in order to place in opposition the earliest and the more recent attempts at generalisation. In the intellectual movement which has taken place in the course of centuries, and which in reference to the enlargement of the domain of cosmical contemplation was described in another portion ([27]) of the present work, the end of the 13th and beginning of the 14th centuries were particularly distinguished; but the Opus Majus of Roger Bacon, the Mirror of Nature of Vincentius of Beauvais, the Physical Geography (Liber Cosmographicus) of Albertus Magnus, the Picture of the World (Imago Mundi) of Cardinal Petrus de Alliaco, (Pierre d'Ailly), are works which, however powerfully they may have influenced their cotemporaries, do not correspond in their contents to the titles which they bear. Among the Italian opposers of Aristotle's Physics, Bernardino Telesio of Cosenza was the founder of a "Rational" system of natural science, in which he regarded all the phænomena of matter, itself passive, as

the effects of two incorporeal principles, (activities, forces, or powers,) heat and cold. Even the whole of organic life, ("animated" plants and animals) is the production of these two eternally-divided forces, one of which, heat, belongs to the celestial, and the other, cold, to the terrestrial sphere.

With fancy still more unregulated, but gifted with a profound spirit of research, Giordano Bruno of Nola attempts in three works entitled "De la Causa Principio e Uno," "Contemplationi circa lo Infinito, Universo e Mondi innumerabili," and "De Minimo et Maximo," to embrace the entire Universe. ([28]) In the "Natural Philosophy" of Telesio, a cotemporary of Copernicus, we perceive at least the endeavour to reduce the variations of matterto two of its fundamental forces, "which are indeed imagined as acting from without," yet are similar to the fundamental forces of attraction and repulsion in the dynamic doctrines of Boscovich and Kant. The cosmical views of Giordano Bruno are purely metaphysical; they do not seek the causes of sensible phænomena in matter itself, but touch on "the infinity of space filled with self luminous worlds, the animation of these worlds by souls, and the relations of the highest Intelligence, God, to the universe." Although himself but scantily furnished with mathematical knowledge, Giordano Bruno was, nevertheless, up to the time of his dreadful martyrdom, ([29]) an enthusiastic admirer of Copernicus, Tycho Brahe, and Kepler. Although a cotemporary of Galileo, he died before the invention of the telescope by Hans Lippershey and Zacharias Jansen, and could not therefore witness the discovery of Jupiter's satellites, the phases of Venus, and the nebulæ. With daring confidence in what he termed "lume interno, ragione naturale, altezza dell' intelleto," he gave himself up to happy

conjectures respecting the movement of the fixed stars, the planetary nature of comets, and the deviation of the figure of the Earth from that of a perfect sphere. (30) Grecian antiquity is also full of such uranological divinations, which have been subsequently realised.

In the development of thought respecting cosmical relations of which the leading forms and epochs have been here enumerated, it was Kepler who, fully 78 years before the publication of Newton's immortal work of the "Principia Philosophiæ naturalis," came nearest to a mathematical application of the doctrine of gravitation. Although the Eclectic Simplicius expressed in a general manner that "the non-falling of the heavenly bodies was caused by the centrifugal force having the upper hand of the proper falling force, the downward traction;"—although John Philoponus, a disciple of Ammonius, the son of Hermeas, ascribed the movements of the heavenly bodies "to a primitive impetus and to the continued tendency to fall;"—and although Copernicus, as was noticed in an earlier part of the present work, describes the merely general idea of gravitation, as it acts in the Sun as the centre of the planetary world, and in the Earth and Moon, in these remarkable words: "Gravitatem non aliud esse quam appetentiam quandam naturalem partibus inditam a divina providentia opificis universorum, ut in unitatem integritatemque suam sese conferant, in formam globi coëuntes;" yet it is in Kepler, in the Introduction to the book "De Stella Martis," (31) that we first find numerical quantities assigned to the attracting forces which the Earth and the Moon exercise upon each other in the ratio of their masses. It distinctly adduces the ebb and flow of the sea (32) as a proof that the attracting power of the Moon, (virtus

tractoria) extends as far as the Earth; and he even says that this force, "similar to that which the magnet exercises upon iron," would deprive the Earth of water, if the Earth itself ceased to attract the water. Unfortunately, ten years later, in 1619, this great man, perhaps out of deference to Galileo, who ascribed the ebb and flow to the rotation of the Earth, gave up the true explanation, and in the Harmonice Mundi described the Earth as a living animal whose whale-like respirations, in periodical alternations of sleeping and waking dependent on the solar time, cause the swelling and sinking of the ocean. The profound mathematical genius, recognised by Laplace, which shines forth in one of Kepler's writings (33), makes us regret that the discoverer of the three great laws of all planetary movement did not persevere in the path, in which his views respecting the attraction of masses had led him to enter.

Descartes, furnished with a greater variety of knowledge in the natural sciences than Kepler, and himself the founder of several parts of a mathematical system of physics, undertook to embrace the whole world of phænomena, the celestial sphere, and all that he knew of animate and inanimate terrestrial Nature, in a work to which he gave the names of "Traité du Monde" and "Summa Philosophiæ." The organization of animals, and particularly that of man, for the understanding of which he pursued for eleven years a systematic course of anatomical study, (34) was to form the concluding portion of the work. In his correspondence with Father Mersenne, we find many complaints of the slow progress of the undertaking, and of the difficulty of arranging and combining such numerous materials. This Cosmos, which Descartes always called his World (son

Monde), was finally to have been sent to press at the conclusion of 1633; but the report of the sentence passed upon Galileo in the Inquisition at Rome (which was only made known four months later, in October, 1633, by Gassendi and Bouillaud), arrested its progress, and deprived the world of a great work, executed with so much labour and care. The motives for its non-publication were the love of a quiet and peaceful life in his retirement at Deventer, and a pious anxiety not to shew himself disrespectful to the Pope's decree against the Earth's planetary motion. (35) It was not until 1664, fourteen years after the philosopher's death, that some fragments of the work were printed under the strange title of "Le Monde, ou Traité de la Lumière." (36) The three chapters which treat of Light hardly form a fourth part of the whole. On the other hand the sections which belonged originally to Descartes' Cosmos, and contained considerations on the motion and solar distance of the planets, on terrestrial magnetism, on tides, and on earthquakes and volcanoes, were transferred to the third and fourth parts of the celebrated work entitled "Principes de la Philosophie."

The "Kosmotheoros" of Huygens, which was not published until after his death, notwithstanding its high-sounding and significant name, hardly deserves to be mentioned in this enumeration of cosmical essays. It contains the dreams and conjectures of a great man on the vegetable and animal worlds of distant heavenly bodies, and especially on the altered forms under which mankind may appear there. One seems to be reading Kepler's "Somnium Astronomicum," or Kircher's "Ecstatic Journey." As Huygens already, like the astronomers of the present day, allowed to

the Moon neither air nor water, (37) he finds the supposed existence of lunar men present to him still greater difficulties than that of the inhabitants of the remoter planets "rich in clouds and vapour."

The immortal author of the Philosophiæ Naturalis Principia Mathematica, succeeded, by the assumption of a single all-governing fundamental moving force, in embracing the whole uranological portion of the Cosmos in the causal connection of its phænomena. Newton first raised physical astronomy to a mathematical science, and made it the solution of a great problem of mechanics. The quantity of matter in each heavenly body gives the measure of its attracting force, a force which acts in the inverse ratio of the square of the distance, and determines the magnitude of the perturbing actions which not only the planets, but all the heavenly bodies in space, exert upon each other. But the Newtonian theorem of gravitation, so admirable for simplicity and generality, is not limited in its cosmical application to the sphere of uranology; it governs also terrestrial phænomena in directions still partly uninvestigated; it gives the key to periodic movements in the ocean and in the atmosphere, (38) to the solution of problems of capillarity, endosmose, and many chemical electro-magnetic and organic processes. Newton himself (39) already distinguished the "attraction of mass," as it manifests itself in all celestial bodies and in the phænomena of the tides, from "molecular attraction," which acts at infinitely small distances and in the closest contact.

Thus among all human efforts to reduce all variations taking place in the world known to us through our senses to a single fundamental principle, the doctrine of gravita-

tion shews itself the most comprehensive and the most rich in cosmical promise. It is indeed true, notwithstanding the brilliant progress made in modern times in Stœchiometry (calculation of chemical elements and of the ratios of volume in compound gases), we are not yet able to reduce all theories of substances to a mathematical explanation. Empirical laws have been discovered, and in following the widely extended views of the atomic or of the corpuscular philosophy, many things have been rendered more accessible to mathematical treatment; but from the boundless heterogeneity of matter, and the multifarious conditions of aggregation of what are called the particles of mass, the demonstrations of these empirical laws can as yet by no means be derived from the theory of "contact attraction," with the same certainty as is effected by the establishment of Kepler's three great laws on the basis of the theory of "mass attraction" or gravitation.

Yet, after Newton had recognised all the motions of the heavenly bodies as consequences of one single force, he did not, with Kant, regard gravitation itself as an essential property of matter, [40] but as either derived from a higher force still unknown to him, or as the result of a "revolving of the Ether which fills all space, and is more rare in the intervals between the particles of mass, and increases in density outwards." The latter view is developed in detail in a letter to Robert Boyle, [41] dated 28th February, 1678, which ends with the words, "I seek in the Ether the cause of gravitation." Eight years later, as may be seen from a letter to Halley, Newton gave up this hypothesis of denser and rarer Ether altogether. [42] It is a striking circumstance that, in 1717, nine years before his death, in the extremely

short preface to the second edition of his Optics, he thought it necessary to declare explicitly that he by no means regarded gravitation as an "essential property of bodies": [43] while more than a century before, in 1600, Gilbert had viewed magnetism as a force inherent in all matter. So much did the most profound of thinkers, Newton himself, who ever leaned so strongly to experience, hesitate in respect to the "ultimate mechanical cause" of motion.

The establishment of a science of Nature, from the laws of gravity up to the formative impulse in animated bodies, as one organic Whole, is no doubt a brilliant problem, and one worthy of the human intellect; but the imperfect state of so many parts of our knowledge places insuperable difficulties in the way of its solution. The impossibility of complete experimental knowledge, in a boundless sphere of observation, renders the problem of explaining all the changes of matter from the powers of matter itself an "indeterminate problem." What is perceived is far from exhausting what is perceivable. If, to recall only the progress of the time nearest to our own, we compare the imperfect knowledge of nature possessed by Gilbert, Robert Boyle, and Hales with the present, and if we remember that the rate of progress is a rapidly increasing one, we may have some idea of the periodical endless transformations which still await all the physical sciences. New substances and new powers will be discovered. Even though many natural processes, as those of light, heat, and electro-magnetism, being reduced to movement (undulations), have become accessible to mathematical treatment, yet there remain the often referred to, and perhaps unconquerable, problems of the cause of chemical diversity of substance,

and of the order and proportions, seemingly not reducible to any laws, of the magnitudes, densities, inclinations of axis, and eccentricities of orbit of the planets, the numbers and distances of their satellites, the form of continents, and the position of their loftiest mountain chains. All these circumstances (having reference to space geographical or celestial), which are here instanced merely as examples, can as yet only be regarded as natural facts, of which we know the existence but not the explanation. But although neither the causes nor the connection of these facts are yet known to us, I do not therefore term them in any sense accidental. They are doubtless the results of events or occurrences in space at the time of the formation of our planetary system, and of geological phænomena which accompanied or preceded the elevation of the outermost strata of our globe into continents and mountain chains. Our knowledge of the early period of the physical history of the Universe does not reach back far enough to enable us to describe that which exists in its process of formation. ([44])

But although it has not yet been possible in all cases fully to recognise the causal connection between phænomena, no part of the domain of the natural sciences can be excluded from the study of the Cosmos, or the physical description of the Universe. Rather that study comprehends the whole of such domain, the phænomena of both spheres, celestial and telluric; but it does so only under the single point of view of the tendency towards the recognition of the Universe as a Whole. ([45]) As, in the description of what has taken place in the moral and political sphere, the historian ([46]) cannot directly discern, according to man's view, the plan of the government of the world,

but can only divine it through the ideas by which it manifests itself; so the investigator of nature, in seeking to present cosmical relations, is penetrated by the conviction that the number of impelling, forming, and producing powers or forces of the material universe, is far indeed from having been exhausted by the results hitherto obtained, either by immediate observation, or by the analysis of phænomena.

# A.

## RESULTS OF OBSERVATION IN THE URANOLOGICAL PORTION OF THE PHYSICAL DESCRIPTION OF THE UNIVERSE.

We commence afresh with the depths of space and with the remote sporadically-scattered clusters of stars which present themselves to telescopic vision as faintly shining nebulæ. We descend step by step to the double stars, often of two different colours, which revolve around a common centre of gravity; to the nearer strata of stars, one of which appears to include our planetary system; and lastly, through this planetary system to the air- and sea-surrounded spheroid which we inhabit. I have noticed in an earlier volume, in the introduction to the general picture of Nature,(47) that this order is the only one which is suitable to the particular character of a work which treats of the Cosmos; in contradistinction to an arrangement more directly accordant with the immediate perceptions of sense, which should begin with our terrestrial dwelling-place and the organic creation by which its surface is enlivened, and should proceed from the apparent to the real motions of the heavenly bodies.

The uranological domain, as opposed to the telluric, divides itself conveniently into two portions: one of which

includes Astrognosy, or the heaven of the fixed stars; and the other, our solar and planetary system. The imperfect and unsatisfactory character of this nomenclature and these definitions need not be again dwelt on here. Names were introduced into the natural sciences before the true differences and distinctions between objects were sufficiently known.(48) Such questions are, however, of less importance than the connection of ideas, and the order in which the objects are to be treated; whilst novelties in the names of groups, and the diversion of names in frequent use from the signification they have hitherto borne, are objectionable, as tending to perplexity and confusion.

### a. *Astrognosy* (*heaven of the fixed stars*).

Nothing in space is in repose; not even what are called the fixed stars, as Halley(49) first attempted to shew in the case of Sirius, Arcturus, and Aldebaran, and as has been proved incontestably in modern times in the case of many other stars. In the course of 2100 years of observation (since Aristillus and Hipparchus), the bright star Arcturus has altered its place, relatively to the neighbouring fainter stars, as much as two and a half times the diameter of the moon. Encke remarks that the star $\mu$ in Cassiopea would appear to have moved three and a half times, and the star 61 Cygni six times, the diameter of the moon from their respective places, if we regard the old observations as sufficiently exact to justify the conclusion. Inferences based on analogies support the conjecture that progressive, and probably also rotatory, motion exists everywhere. The name "fixed star" leads to erroneous suppositions; whether it be taken in its

first signification among the Greeks of set or fixed in the crystal firmament, or according to the later and more Roman interpretation of steadfast, resting, and immoveable. One of these ideas necessarily implied and led to the other. In Grecian antiquity (at least going back as far as Anaximenes, who belonged to the Ionic school, or as the Pythagorean Alcmæon), all the stars or heavenly bodies were divided into moving (ἄστρα πλανώμενα or πλανητά) and non-moving stars (ἀπλανεῖς ἀστέρες or ἀπλανῆ ἄστρα). (50) Besides this latter generally employed term, which Macrobius latinises in the Somnium Scipionis by Sphæra aplanes,(51) we find in Aristotle repeatedly (as if he wished to introduce a new technical term) the name of ἐνδεδεμένα ἄστρα, instead of ἀπλανῆ. (52) From this form of expression there followed, with Cicero, sidera infixa cœlo; with Pliny, stellas quas putamus affixas; and with Manilius, even astra fixa, just like our "fixed stars." (53) The idea of being fixed or set in the solid sky, led to the secondary implied idea of immobility, or "remaining fixed in one place;" and thus, in Latin versions, throughout the whole middle ages, the original meaning of the word infixum or affixum sidus, was gradually set aside, and the idea of immobility alone retained. We find the impulse to this already given in the highly rhetorical passage of Seneca (Nat. Quæst. vii., 24), on the possibility of discovering new planets: "credis autem in hoc maximo et pulcherrimo corpore inter innumerabiles stellas, quæ noctem decore vario distinguunt, quæ aëra minime vacuum et inertem esse patiuntur, quinque solas esse, quibus exercere se liceat; *ceteras stare fixum et immobilem populum?*" This "quiet, immoveable people" is nowhere to be found.

In order to divide conveniently into groups the principal results of actual observation, and the conclusions or conjectures to which they lead, I propose to distinguish, in the astrognostic portion of the description of the Universe, the following heads:—

I. Considerations on space, and on what is supposed to occupy it.

II. Natural and telescopic vision; the scintillation of stars; the velocity of light; and photometric experiments on the intensity of sidereal light.

III. The number, distribution, and colour of stars; clusters of stars; and the milky way, in which are only a few nebulæ.

IV. Newly appeared stars; vanished stars; and stars which vary periodically.

V. The proper motion of the fixed stars; the problematical existence of dark bodies; the parallax and measured distance of some fixed stars.

VI. Double stars, and their periods of revolution round a common centre of gravity.

VII. Nebulæ, which in the Magellanic clouds are intermixed with many clusters of stars; and the black spots or patches in the sky ("coal-bags").

# I.

## COSMICAL SPACE, AND CONJECTURES RESPECTING WHAT APPEARS TO OCCUPY THE INTERVALS BETWEEN THE HEAVENLY BODIES.

We may in some respects view a commencement of the physical description of the Universe, by the consideration of what fills the intervals between the stars in the remote regions of space and remains inaccessible to our organs, in the same light as mythical commencements of the world's history. In infinite space, as in infinite time, everything appears in uncertain and often illusive twilight. Imagination is then doubly stimulated to draw from her own abundance, and to give to the indeterminate and varying forms outline and duration. (54) Such an avowal may, I hope, suffice to shield me from the reproach of having confounded what direct observation or measurement have raised to mathematical certainty, with what rests only on very imperfect induction. Wild reveries belong to the romance of physical astronomy: nevertheless, minds exercised in scientific labour may dwell, not without pleasure, on questions which, in connection with the present state of our knowledge and the hope which this state excites, have been deemed by some of the most distinguished

astronomers of the present day worthy of serious examination.

It may be assumed with great probability that we are in communication, through the influence of gravitation and through light and radiant heat,(55) not only with our own sun, but also with all the other shining suns of the firmament. The important discovery of the measurable resistance opposed by a space-filling fluid to a comet of a five years' period of revolution, has been completely confirmed by exact numerical accordances. Inferences founded on analogies may serve to fill a part of the wide chasm which separates the assured results of a mathematical natural philosophy, from conjectures directed to the extreme, and therefore obscure and desert, boundaries of all scientific development of thought.

From the infinity of Space, which indeed was doubted by Aristotle,(56) follows its immeasurability. Only separate parts have been accessible to measurement; and the results, which surpass all our powers of realisation, are brought together with complacency by those who take a childish pleasure in large numbers, and even imagine that, by means of images of physical magnitude creating astonishment, they peculiarly enhance the sublimity of astronomical studies. The distance of the star 61 Cygni from the sun is 657000 semi-diameters of the earth's orbit,—a distance which light takes rather more than ten years to traverse, whilst it comes from the sun to the earth in 8 minutes 17·78 seconds. Sir John Herschel conjectured, from an ingenious combination of photometric estimations, (57) that, supposing stars of the milky way which he saw glimmer in his twenty-foot telescope to be newly formed luminous bodies, they would have required 2000 years thus to have sent us their

first ray of light. All attempts to bring such numerical relations home to our imaginations fail, either from the vastness of the unit of measure employed, or from the vastness of the number of its repetitions. Bessel said very truly (58) "that the distance which light travels in one year can no more be rendered sensible to us than the distance which it traverses in ten years: no endeavours to bring home to our imagination a magnitude far exceeding all magnitudes accessible on the earth are ever successful." We find the oppressive power of numbers exceeding what our conceptions can grasp, alike in the smallest organized beings of animal life, and in the galaxy of self-luminous suns which we term fixed stars. What a mass of Polythalamia are contained, according to Ehrenberg, in a thin stratum of chalk! Of the microscopic Gaillonella distans, according to the same great inquirer into nature, a cubic inch of the Bilin polishing slate, which forms a dome 40 feet high, contains 41000 millions of individuals. Of Gaillonella ferruginea, one cubic inch contains upwards of 1 billion 750000 millions. (59) Such estimations remind us of the Arenarius (ψαμμιτης) of Archimedes, of the grains of sand which might fill Space! If, in considering the starry heavens, impressions of vast magnitudes in space and time, which numbers convey but imperfectly, remind man of his smallness of stature, his physical weakness, and the ephemeral duration of his earthly existence,—he is, on the other hand, cheered and invigorated by the consciousness, that the application and development of the human intellect have already made known to him such important portions of the subjection of nature to definite laws, and so much of the sidereal order of the universe.

If we assume that the spaces between the heavenly bodies

are not a vacuum,(60) but are filled with some kind of matter, —as not only the propagation of light, but also a particular effect of its enfeeblement, as well as the influence of a resisting medium on the period of revolution of Encke's comet, and the dissolution of many vast tails of comets, appear to shew,— it is necessary to take the precaution of reminding the reader that the term "ether" now employed, and which has come to us from the earliest south and west Asiatic antiquity, has not during so many centuries always conveyed the same ideas. With the Indian philosophers the æther (âkâ'sa) is one of the "pantschatâ" or five elements, a fluid of infinite rarity pervading the entire universe, and the exciter of life, as well as the medium of the propagation of sound.(61) Etymologically, "âkâ'sa" signifies, according to Bopp, "shining," and therefore in its original meaning approaches the æther of the Greeks as nearly as "shining" does "burning."

This æther (αιθηρ), according to the dogmas of the Ionian philosophy, and according to Anaxagoras and Empedocles, was altogether different from the thicker (denser), vapour-filled, true air (ἀηρ), which surrounds the earth "and perhaps extends to the moon." It was "of a fiery nature, a pure fiery atmosphere, bright beaming(62), of great tenuity (rarity) and eternal serenity." The etymological derivation from "burning" (αιθειν) accords perfectly with this definition. Singularly enough, out of predilection for mechanical views, and referring to the constant revolving motion, it was subsequently changed by Plato and Aristotle, by a play upon words, into another derivation, αει θεῖν.(63) The idea of the rarity and thinness of this upper air, the æther, does not appear to have been a consequence of the

knowledge of the purer mountain air, comparatively free from heavy terrestrial vapours; or of the diminishing density of the strata of air with increasing height. As the "elements" of the ancients signify not so much diversity, or even simplicity or indecomposability of substance, as "states of matter," the idea of the upper æther (the fiery celestial atmosphere) had its root in the first and normal antitheses of "heavy" and "light," "under" and "upper," "earth" and "fire." Between these two extremes are two "middle elementary states:" water, more nearly akin to the heavy earth; and air, nearer to the light fire.(64)

As a space-filling medium, the æther of Empedocles has no analogy, excepting by its tenuity and rarity, with the ether by whose transverse vibrations modern physical science has succeeded so happily in explaining, by pure mathematical deduction, the propagation of light and all its properties (double refraction, polarisation, and interference). In the natural philosophy of Aristotle it was also taught that the æthereal substance pervaded and penetrated all organic beings, plants, and animals; that it became in them the principle of vital heat, and even the germ of a psychical principle, which, preserving itself distinct from the body, awakened men to self-activity.(65) These imaginations draw down the æther from upper space into the terrestrial sphere; they present it as an exceedingly fine substance constantly pervading and penetrating both the atmosphere and solid bodies, as does the ether in the undulatory theory of light, according to the views of Huygens, Hooke, and our present physicists. But that which most directly distinguishes the two hypotheses, the ancient Ionian æther and the modern ether, from each other, is the original assumption (not altogether shared, however,

by Aristotle), in regard to the former, of self-luminosity. The upper fiery atmosphere of Empedocles is expressly called "bright beaming" (παμφανόων), and in certain phænomena was supposed to be seen by the inhabitants of the earth as the brightness of fire through clefts and rents (χάσματα) opened in the firmament. (66)

In the intimate relations between light, heat, electricity, and magnetism, now so much examined, it is deemed probable that, as the transverse undulations of the space-filling ether produce the phænomena of light, so thermic and electro-magnetic phænomena depend on analogous kinds of motion (currents). Great discoveries on these subjects are no doubt reserved to future times. Light, and radiant heat inseparable from light, are, to the non-luminous cosmical bodies, and to the surface of our own planet, a principal source of motion and of all organic life. (67) Even remote from the surface, in the interior of the crust of the earth, the heat which penetrates inwards calls forth electro-magnetic currents, which exercise their exciting influence on combinations and decompositions of substances, upon all formative activity in the mineral kingdom, and on the disturbance of equilibrium in the atmosphere, as well as on the functions of vegetable and animal organisms. If electricity moving in currents developes magnetic forces,—if, according to an earlier hypothesis of Sir William Herschel, (68) the sun itself is in the condition "of a perpetual Aurora" (I should say of an electro-magnetic storm), it would not appear an inappropriate conjecture to suppose that in space also, the light of the sun, propagated by vibrations of the ether, may be accompanied by electro-magnetic currents.

It is true that in terrestrial magnetism direct observation

of the periodical variations of declination, inclination, and force, has not as yet disclosed with certainty any influence from the different positions either of the sun or of the nearer moon.* The magnetic polarity of the earth does not shew oppositions which relate to the sun, and are sensibly affected by the precession of the equinoxes. (69) Only the remarkable varying direction of the cone of light which streamed from Halley's comet, and which Bessel observed from the 12th to the 22d October, 1835, and sought to interpret, had persuaded that great astronomer of the existence of a polar force,—" of the action of a force differing materially from gravitation or the ordinary attracting power of the sun, since those portions of the comet which form the tail experience the effect of a repelling force from the body of the sun." (70) The fine comet of 1744, which was described by Heinsius, had also given occasion to similar conjectures on the part of my deceased friend.

The action of radiant heat is regarded as less problematical than electro-magnetic agencies in space. According to Fourier and Poisson, the temperature of space is the result of the radiation of heat from the sun and all the heavenly bodies, diminished by the absorption which the heat suffers in traversing space filled with "ether." (71) The "heat of the stars" was spoken of on many occasions by the ancients (the Greeks and Romans); (72) not merely because, accord-

* [Since this passage was printed in the German original, the Philosophical Transactions for 1849 have reached M. de Humboldt, containing a memoir in which it is shown that the magnetic observations made in different hemispheres, (at Toronto in Canada, and at Hobarton in Van Diemen Island), concur in indicating that the terrestrial magnetism does undergo an annual variation connected with the sun's position relatively to the earth.—Ed.]

ing to a widely prevalent opinion, the stars belonged to the region of the fiery æther, but because they are themselves of a fiery nature:(73) and Aristarchus, of Samos, even taught that the fixed stars and the sun are of the same nature. In very recent times, through the influence of the two great French mathematicians who have just been named, the interest of an approximate determination of the temperature of space has been more strongly felt, as it has at length been perceived how important, on account of the radiation of heat from the earth's surface to the heavens, was this determination in respect to all thermic relations, and, one might even say, to the habitability of our planet. According to Fourier's analytical theory of heat, the temperature of space (des espaces planétaires ou célestes) is somewhat below the mean temperature of the Pole, or perhaps even somewhat below the lowest temperature hitherto observed in the Polar regions. Fourier estimates it accordingly at from $-50°$ to $-60°$ Cent. ($-58°$ to $-76°$ Fah.) The point of greatest cold (pôle glacial) no more coincides with the pole of the earth than does the "thermal equator" (which connects the warmest points on all meridians) with the geographical equator. Arago concluded the temperature of the north pole, from the gradual decrease of mean temperatures, to be $-25°$ Cent. ($-13°$ F.); the maximum cold observed by Captain Back, in January 1834, at Fort Reliance (lat. 62° 46′), was $-56°{\cdot}6′$ C. ($-69°{\cdot}88$ F.) (74) The lowest known temperature is, I believe, that which Neveroff observed on the 21st of January, 1838, at Jakutsk (lat. 62° 2′). The accurate Middendorff had compared the observer's instruments with his own. Neveroff found the temperature on the day in question, $-60°$ Cent. ($-76°$ F.)

Among the many grounds of uncertainty in respect to a numerical result for the thermic condition of space, is the circumstance, that we cannot yet obtain a mean of the points of greatest cold of the two hemispheres, as we are still so little acquainted with the meteorology of the southern hemisphere, which must bear its part in determining the mean annual temperature. Poisson's view, that, owing to the unequal distribution of heat-radiating stars, different regions of space must have a very different temperature, and that, from the movement of the whole solar system, our globe in traversing warm and cold regions has received its internal heat from without, ([75]) appears to me to have a very low degree of physical probability.

The question whether the thermal condition of space, or the climates of its several regions, are exposed in the course of long periods of time to great changes of temperature, depends principally on the solution of a question proposed and discussed with great animation by Sir William Herschel: viz. are the nebulæ subject to progressive processes of formation, by condensation taking place according to the laws of attraction around one or several nuclei? If such a condensation of cosmical nebulous matter take place, there must be, in every transition of gaseous or fluid substances to solids, disengagement of heat. ([76]) If, according to the latest views, and from the important observations of the Earl of Rosse and Mr. Bond, it becomes probable that all nebulæ, even those which have not yet been entirely resolved by the greatest power of optical instruments, are thickly crowded clusters of stars, the belief in this perpetually-arising production of heat will indeed be somewhat shaken. But even small solid bodies, seen in telescopes as distinguishable shining points, may

also alter their density in combining into larger masses; and many phænomena which our own planetary system presents lead to the supposition that the planets have been condensed from a state of vapour, and that their internal heat is owing to this process.

At first sight it seems hazardous to assert that a temperature of space so very low as between the freezing points of mercury and of spirits of wine, can be deemed, even indirectly, *beneficial* to the habitable climates of the globe, and to the life of plants and animals; but in order to be satisfied of the correctness of the expression it is sufficient to reflect on the influence of the radiation of heat from the earth. The surface of our globe warmed by the solar heat, and the atmosphere up to its outermost stratum, radiate freely towards space. The loss of heat which they suffer arises from the difference of temperature between the air and space, and the feebleness of the return which they receive. How enormous would be the loss (77) if space, instead of the temperature which we express by −60° Cent. (−76° F.), had, for example, a temperature of −800° Cent. (−1408° F.), or even several thousand degrees lower!

There still remain to be developed two more considerations in reference to the existence of a fluid throughout space: one, less well-established, relates to a "limit to the transparency of space;" the other, based on direct observation, and affording numerical results, to the regular diminution of the period of revolution of Encke's comet. Olbers of Bremen, and, as Struve has remarked, Loys de Cheseaux at Geneva, eighty years before, (78) called attention to the dilemma,—that as in infinite space no point can be imagined

which should not present a fixed star (*i. e.* a sun), either the entire vault of heaven, if light arrived to us quite unenfeebled, must appear as luminous as our sun; or, if this be not so, that we must assume an enfeeblement of light in its passage through space, or a decrease of the intensity of light greater than in the inverse ratio of the square of the distance. Now, since we do not see such an almost uniform brightness covering the heavens (to which Halley (79) also alludes in reference to an hypothesis which he rejects), therefore, in the view of Cheseaux, Olbers, and Struve, we must assume that space is not absolutely and perfectly transparent. Results which Sir William Herschel derived from his star gaugings, (80) and from ingenious investigations on the space-penetrating power of his great telescope, appear to establish that, if the light of Sirius lost only $\frac{1}{800}$ on its way to us in passing through a gaseous or ethereal fluid, this loss, which would give the measure of the density of a light-enfeebling fluid, would suffice to explain phenomena as they present themselves. Amongst the grounds of doubt which the illustrious author of the new "Outlines of Astronomy" opposes to the supposition of Olbers and Struve, one of the most important is, that in the greater part of the milky way, in both hemispheres, his twenty-foot telescope shews him the smallest stars projected on a black ground. (81)

A better proof of the existence of a resisting fluid, (82) and one, as I have already said, founded on direct observation, is furnished by Encke's comet, and by the ingenious and highly important conclusions to which it has conducted its discoverer. The impeding medium must, however, be conceived to be different from the all-penetrating ether whose

undulations propagate light, because resistance implies non-penetration of what is solid. The observations require for the explanation of the diminished period of revolution, (the diminished major axis of the ellipse), a *tangential force;* and this is supplied in the most direct manner by the assumption of a resisting fluid. ([83]) The greatest effect shows itself in the twenty-five days next before the passage of the comet through its perihelion, and in the twenty-five days which follow the passage. Thus the value of the constants is somewhat different, because near the sun, the so rare, but yet gravitating, strata of the resisting fluid are denser. Olbers ([84]) was of opinion that the fluid could not be in repose, but must rotate from right to left round the sun; and, therefore, the resistance to retrograde comets, like Halley's, must be quite different from the resistance to a comet whose motion is direct, as Encke's. The calculation of perturbations in comets of long period, and the differences of masses and magnitudes of the comets, complicate the results, and mask what may be due to particular causes.

The nebulous or vaporous matter which forms the ring of zodiacal light, may be, perhaps, as Sir John Herschel expresses it, only the denser part of the comet-resisting medium itself. ([85]) Even supposing it were already proved that all nebulæ are only imperfectly-seen crowded clusters of stars, there yet remains the fact, that innumerable comets, by the dissolution of their tails of more than fifty millions of miles in length, fill space with a material substance. Arago has ingeniously shown from optical considerations, ([86]) that the variable stars which in their periodical phases always show white light, without any trace of colour, might

furnish a means of determining the superior limit of the density ascribable to the ether, if we assume it to resemble terrestrial gaseous fluids in its powers of refraction.

Connected with the question of the existence of a space-filling ethereal fluid, is the one proposed with so much animation by Wollaston, (87) of the limit of the atmosphere,—a limit which must exist at the height where the specific elasticity of the air and the attraction of gravitation are in equilibrium. Faraday's ingeniously devised experiments upon the limit of an atmosphere of mercury,—on the height which vapour of mercury tested by amalgamation with gold-leaf scarcely appears to reach in air,—have given increased weight to the hypothesis of a definite surface of the atmosphere, "similar to the surface of the sea." May gaseous substances from space mix with our atmosphere and produce meteorological changes? Newton (88) has touched this question, leaning to the affirmative side. If shooting stars and meteoric stones are regarded as planetary asteroids, we may well hazard the conjecture that, with the streams of myriads of shooting stars which traversed the sky in the month of November, (89) in the years 1799, 1833, and 1834, and when Auroras were observed at the same time,—the atmosphere received from space something which was extraneous to itself, and which might excite electro-magnetic processes.

# II.

## NATURAL AND TELESCOPIC VISION—SCINTILLATION OF STARS —VELOCITY OF LIGHT—RESULTS OF PHOTOMETRY.

It is only within the last two centuries and a half that the artificial telescopic enhancement of the visual power of the eye,—the organ by which we contemplate the Universe,—has afforded the grandest of all aids and instruments for the recognition of the contents of space, and for the discovery of the form, physical constitution, and mass of the planets and of their satellites. The first telescope was constructed in 1608, seven years after the death of the great observer Tycho Brahe. Jupiter's satellites, the solar spots, the phases of Venus, Saturn's ring, telescopic clusters of stars, and the nebula in Andromeda, (90) had already been successively discovered by means of the telescope, when, in 1634, the French astronomer Morin (worthy of honourable mention in reference to observations of longitude), thought of attaching a telescope to the alidade of a measuring instrument, and looking for Arcturus in the day-time. (91) The improvement of the graduation of the limbs of instruments would have failed, either wholly or in great part, in attaining its principal object, viz. greater precision in obser-

vation, if optical means had not been adopted for augmenting the exactness of the reading commensurately with that of the measurement. The construction of micrometers with fine threads stretched in the focus of the telescope, the application of which first gave to more exact graduation its peculiar and indeed inestimable value, was devised six years afterwards, in 1640, by the young and talented Gascoigne. (92)

While, therefore, in astronomical researches, telescopic observation and measurement include only 240 years, we may reckon, (without reference to the Chaldeans, Egyptians, and Chinese, and counting only from Timochares and Aristillus (93) to the discoveries of Galileo), more than nineteen centuries in which the position and movements of the heavenly bodies were observed with the naked eye. Seeing the numerous interruptions to which the progress of civilisation and knowledge among the nations surrounding the Mediterranean was exposed during that long period, we must regard with surprise and admiration the recognition by Hipparchus and Ptolemy of the intricate movements of the planets, of the two principal lunar inequalities, and of the places of the stars; the perception, by Copernicus, of the true system of the universe; and the improvement, by Tycho Brahe, of practical astronomy and its methods,—all antecedent to the invention of the telescope. Exactness of observation may doubtless have been somewhat increased by the employment of long tubes, used most probably by the ancients and certainly by the Arabs, and arranged so that the object was seen through dioptra or narrow apertures. Abul Hassan speaks decidedly of tubes having eye and object dioptra attached to the extremities; and this arrangement was also employed at the observatory esta-

blished by Hulagu at Meragha. If looking through tubes facilitates the finding of stars in the twilight,—in other words, if, in the evening twilight, stars are earlier visible to the naked eye with tubes than without,—the reason, as Arago has remarked, is, that the tube, when the eye is kept close to it, cuts off a large portion of the disturbing diffused light (rayons perturbateurs) of the atmospheric strata which intervene between the star and the eye. In like manner, even in a dark night, the tube is useful in preventing the lateral impression of the faint light which the particles of air receive from all the other stars in the sky; the intensity of the luminous image and the size of the star thus appear increased. In a much amended, and often contested, passage of Strabo, in which there is a reference to looking through tubes, the enlarged appearance of the stars, or heavenly bodies, is expressly mentioned, although erroneously attributed to refraction.(94)

Light, from whatever source it may pröceed,—whether from the sun, as solar light, or as reflected by the planets; from the fixed stars; from rotten wood; or as the product of vital activity in glow-worms and other luminous animals,—always shows the same refractive properties. (95) But the prismatic coloured images, or spectra, from different sources of light, (from the sun and from the fixed stars), show a difference in the position of the dark lines, which were first discovered by Wollaston in 1808, and of which Fraunhofer determined the position with great exactness twelve years later. Fraunhofer had counted 600 dark lines (properly speaking, interruptions, or defective parts, of the coloured image or spectrum): in the fine experiments of Sir David Brewster with nitrous acid gas, in 1833, their number rose to above 2000. It had been remarked that, at certain seasons

of the year, particular lines were wanting; but Brewster has shewn that this is a consequence of the different height of the sun, and the different absorption of the rays of light in their passage through the atmosphere. In the coloured spectra given by the reflected light of the Moon, Venus, Mars, and the Clouds, we find, as would no doubt have been expected, all the characteristics of the solar spectrum. On the other hand, the dark lines of the spectrum of Sirius differ from those of Castor or of other fixed stars. Castor himself shows other lines than those shown by Pollux and Procyon. Amici has confirmed these differences, which had already been indicated by Fraunhofer, and has called attention to the fact that, in fixed stars of at present equal and perfectly-white light, the dark lines are not the same. There still remains here a wide and important field for future research, (96) in order to separate what is certain from what is rather to be termed accidental—dependent on the absorbing effect of the atmosphere.

There is another phænomenon deserving to be here noticed, in which the specific character of the source of light has a powerful influence. The light of glowing solid bodies and that of the electric spark show great variety in the number and position of Wollaston's dark lines. According to Wheatstone's remarkable experiments with revolving mirrors, the light of friction-electricity appears also to have a velocity greater than that of solar light, in the ratio of at least 3 to 2 (or fully 83920 geographical miles in a second of time).

A new life has animated all departments of optics from the time when (in 1808) the reflection of the light of the setting sun from the windows of the Palais du Luxembourg accidentally led the acute Malus to the important dis-

covery of polarisation. (97) Since that event, the more deeply-examined phænomena of double refraction, ordinary (Huygenian) polarisation and coloured polarisation, interference, and diffraction, have furnished the investigator with unexpected means of distinguishing between direct and reflected light (98), of penetrating the secret of the constitution of the Solar orb and his luminous envelopes (99), of measuring the pressure and the minutest aqueous contents of the atmosphere, of discerning the bottom of the sea and its shoals by the aid of a plate of tourmaline (100), and even of comparing, according to Newton's example, the chemical (101) composition of several substances (102) with their optical effects. It is sufficient to mention the names of Airy, Arago, Biot, Brewster, Cauchy, Faraday, Fresnel, John Herschel, Lloyd, Malus, Neumann, Plateau, Seebeck . . . . . to recall to the recollection of the scientific reader a series of brilliant discoveries, and of the happiest applications of each newly-discovered step. The great works of Thomas Young, marked with the stamp of genius, more than prepared the way for these important labours. Arago's polariscope, and the observed position of coloured diffraction-fringes (consequences of interference), have become of great and varied use in the investigation. Meteorology has profited no less than physical astronomy by the opening of this new path of research.

Different as is the power of vision with the naked eye in different men, yet here also there is a certain mean degree of organic capability, which was the same among the ancient Greeks and Romans as in the present day. The Pleiades furnish the proof of this, showing that some thousand years ago, as now, stars which astronomers call of the 7th magnitude

are not visible to the naked eye in persons of ordinary powers of vision. The group of the Pleiades consists of a star of the 3rd magnitude, Alcyone; two of the 4th magnitude, Electra and Atlas; three of the 5th, Merope, Maia, and Taygeta; two between the 6th and 7th, Pleione and Celæno; one between the 7th and 8th, Asterope; and several very small telescopic stars. I employ the present denominations and order of magnitudes, for among the ancients some of these names were assigned to other stars. It was only the six first-named stars, of the 3rd, 4th, and 5th magnitudes respectively, that could be easily seen. ([103]) Ovid says (Fast. iv. 170): "Quæ septem dici, sex tamen esse solent." It was supposed that one of the daughters of Atlas, Merope, the only one who had married a mortal, remained veiled through bashfulness, or even that she had entirely disappeared. She was probably the star of almost the 7th magnitude, which we now call Celæno; for Hipparchus remarks, in the commentary to Aratus, that in clear moonless nights seven stars could really be perceived. It was then Celæno which was seen as the seventh Pleiad; Pleione, which is of equal brightness, being too near Atlas (a star of the 4th magnitude) to be distinguished.

The small star Alcor (which, according to Priesnecker, is at a distance of 11′ 48″ from Mizar, in the tail of the Great Bear) is, according to Argelander, of the 5th magnitude, but overpowered by the brightness of Mizar. It was called by the Arabs "Saidak," "the tester;" because it was the custom, as the Persian astronomer Kazwini([104]) informs us, "to test a man's power of sight by it." Notwithstanding the low altitude of the constellation of the Great Bear within the tropics, I have seen Alcor with the naked eye with

great distinctness every evening on the rainless coast of Cumana, and on the high plateaus of the Cordilleras at elevations of twelve thousand feet; but I have recognised it only rarely and uncertainly in Europe, and in the dry air of the steppes of Northern Asia. The limit within which it is possible, with the naked eye, to separate two objects very near to each other in the heavens, depends, as Mädler has very justly remarked, on their relative brightness. The two stars of the 3d and 4th magnitudes, marked α Capricorni, which are six and a half minutes apart, are separated without difficulty. Galle thinks it possible, in a very clear atmosphere, to separate with the naked eye ε and 5 Lyræ, though only three and a half minutes apart, because they are both of the 4th magnitude.

The too great comparative brightness of the neighbouring planet is also the principal reason why Jupiter's satellites, (one of which, and not all, as is often erroneously stated, is equal in its light to stars of the 5th magnitude), remain invisible to the naked eye. According to recent estimations and comparisons with neighbouring stars by my friend, Dr. Galle, the third satellite, which is the brightest, may correspond to stars from the 5th to the 6th magnitude; whilst the others correspond, as their light varies, to stars from the 6th to the 7th magnitude. Only occasional instances have been cited of persons of extraordinary keenness of vision, (persons who could perceive distinctly with the naked eye stars below the 6th magnitude), having seen any of Jupiter's satellites without a telescope. The angular distance of the third and brightest satellite from the centre of the planet is 4′ 42″; that of the fourth, which is only 1-6th smaller than the largest, 8′ 16″; and all Jupiter's

satellites have at times, as Arago states, (105) an intenser light, on equal surfaces, than the planet: at times, on the other hand, they appear on the face of Jupiter, as recent observations inform us, as gray spots.

The rays, which appear to our eyes to issue from the planets and from the fixed stars,—and which from the earliest times have been employed in pictorial representations, particularly among the Egyptians, to designate the shining heavenly bodies,—have a length of at least five or six minutes. Hassenfratz declares them to be focal lines, "intersections de deux caustiques," on the crystalline lens. "The image of stars seen by us with the naked eye is enlarged by diverging rays: by reason of this extension it occupies a larger space on the retina than if it were concentrated in a single point. The impression on the nerve is weaker. A very dense cluster of stars, in which all the single stars hardly attain the 7th magnitude, may, on the other hand, become visible to the naked eye, because the images of the many single stars overlap each other on the retina; so that, as in the case of a concentrated image, every sensible point of the latter is more strongly excited." (106).

Telescopes, unfortunately, also give, though in a much less degree, an untrue or spurious diameter to stars: from the examinations of William Herschel, (107) however, these diameters decrease with increased magnifying power. This acute observer, with the enormous magnifying power of 6500, still estimated the apparent diameter of α Lyræ at 0″·36. In terrestrial objects, besides the illumination, the form of the object helps to determine the smallest visual angle under which it can be seen by the naked eye. Adams remarked very justly, that a long thin rod can be seen at a much greater distance than could a square, whose side should

be equal to the thickness of the rod. A line is seen much further than a point, even if the breadths of the two are equal. Arago examined the influence of form in this respect by angular measurements of the lightning conductors visible from the Paris Observatory. Determinations of the smallest optical angle of vision under which terrestrial objects can be recognised by the naked eye have always continued to advance progressively to smaller and smaller quantities ;—from Robert Hook, who declared a full minute to be absolutely necessary, to Tobias Mayer, who required 34″ for a black spot on white paper, and further to Leuwenhoek's spiders' threads, which can be seen by persons of very ordinary powers of vision under an angle of 4″·7. In the most recent and very exact experiments of Hueck on the motion of the crystalline lens, it was barely possible to see white lines on a black ground at an angle of 1″·2, a spider's thread at 0″·6, and a fine shining wire at 0″·2. The problem does not admit of a strict numerical solution, as the result depends on the shape of the objects, their illumination, their contrast with the back ground from which they detach themselves, and the movement or stillness, as well as the nature, of the intervening atmospheric strata.

I was much impressed by a circumstance which occurred during my stay at a beautiful country-seat belonging to the Marques de Selvalegre, at Chillo (not far from Quito), from whence the long extended ridge of the Volcano of Pichincha was seen at a horizontal distance, trigonometrically measured, of 85000 Paris (90590 Eng.) feet. My fellow-traveller Bonpland, who was then engaged alone on an expedition to the Volcano, was recognised by the Indians standing near me as a white point moving along the face of a black ba-

saltic precipice, before we, who were looking for him with telescopes, discovered him. In a short time my companion (the ill-fated son of the Marques, Carlos Montufar, who afterwards fell a victim in the civil war) and myself were also able to distinguish the white moving figure with the naked eye. Bonpland was wrapped in a white cotton mantle, the poncho of the country. Allowing from 3 to 5 feet for the breadth of the shoulders, as the mantle sometimes clung close, and sometimes seemed to fly loosely in the wind, and taking the known distance, we have from 7″ to 12″ as the angle under which the moving object was distinctly seen. White objects on a black ground are seen, according to Hueck's repeated experiments, at a greater distance than black objects on a white ground. The weather was clear, and the ray passed through the stratum of thin air, proper to an elevation of 14412 French (15360 Eng.) feet above the level of the sea, to our station at Chillo, itself 8046 (8575 Eng.) feet high. The distance from the eye to the object was 85596 (91225 Eng.) feet, or 14·8 geographical miles. The heights of the barometer and thermometer at the two stations were very different: at the upper, probably, 194 lines (17·23 English inches), and 8° Cent. (46°.4 Fahr.); and at the lower, by exact observation, 250·2 lines (22·22 English inches), and 18·7 Cent. (65·66 Fahr.) Gauss's heliotropic light, which has become so important an auxiliary in our German trigonometrical measurements, reflected from the Brocken to the Hohenhagen, was seen there at a distance of 213000 French feet (227008 Eng.),—more than 36 geographical miles; and often at points at which the angle subtended by a three-inch mirror only amounted to 0″·43.

The visibility of distant objects is modified by the absorp-

tion of the rays proceeding from the terrestrial object, and arriving at the unassisted eye at different distances, through strata of air more or less dense, and more or less charged with aqueous vapour; by the intensity of the diffused light radiated from the particles of air; and by many still imperfectly explained meteorological circumstances. According to old experiments of the accurate Bouguer, a difference of 1-60th in the intensity of the light is necessary for visibility. We see, as he expresses it, only in a negative manner, hill and mountain summits which radiate but little light, and detach themselves as dark masses against the sky. We see them only by the difference of the thickness of the atmospheric strata, which extend in the one instance to the object, and in the other to the extremest horizon. On the other hand, bright or shining objects, as snowy mountains, white limestone rocks, and cones covered with pumice, are seen in a positive manner. The distance at which high mountain summits can be recognised at sea is not without interest in navigation, when exact astronomical determinations of the ship's place are wanting. I have treated this subject in detail in another place,(108) when discussing the distance at which the Peak of Teneriffe may be visible.

The power of seeing stars with the naked eye in the day-time from the shafts of mines, or on very lofty mountains, has been a subject of examination with me from early youth. I was aware (109) that Aristotle had affirmed that stars could sometimes be seen from vaults and reservoirs, as well as through tubes. Pliny, also, mentions this, and notices at the same time the circumstance that stars can be clearly distinguished in the day-time during solar eclipses. In the course of my professional engagements as a mining engineer, I for some years passed a large portion of every day under ground,

looking up from the bottom of deep shafts to the zenith, but without ever seeing a star; nor have I since found an individual in Mexican, Peruvian, or Siberian mines, who had ever heard of stars being seen in the day-time, although in such different latitudes as those embraced by my inquiries and experience in both hemispheres, a sufficient number of zenith stars must have presented themselves advantageously. This entirely negative evidence renders very remarkable the highly credible testimony of a celebrated optician who, in early youth, saw the stars during bright day-light through a chimney.(110) Phænomena whose visibility depends on an accidental concurrence of favourable circumstances must not be denied because they are of rare occurrence.

This principle also applies, I think, to the statement of the always careful and accurate Saussure, in reference to stars being seen with the naked eye on the ascent of Mont Blanc, at a height of 11970 (12757 Eng.) feet. He says, "Quelques-uns des guides m'ont assuré avoir vu des étoiles en plein jour; pour *moi je* n'y songeois pas, en sorte que je n'ai point été le témoin de ce phénomène; *mais l'assertion uniforme des guides ne me laisse aucun doute sur la réalité.* (111) Il faut d'ailleurs être entièrement à l'ombre, et avoir même au-dessus de la tête une masse d'ombre d'une épaisseur considérable, sans quoi l'air trop fortement éclairé fait évanouir la foible clarté des étoiles." The conditions are, therefore, almost entirely the same as those presented by the reservoirs of the ancients and the chimney before referred to. I have not found this remarkable statement (bearing date the morning of the 2nd of August, 1787) repeated in any subsequent journey in the Swiss mountains. Two highly informed and excellent observers, the brothers Hermann and Adolph Schlagintweit, who have recently explored the

eastern Alps to the summit of the Grosglockner (12213 Fr., or 13016 Eng. feet*), were never able to see stars in the day-time, nor did they hear any statement to that effect among the herdsmen and chamois hunters. I spent several years in the Cordilleras of Mexico, Quito, and Peru, and was very often, together with my friend Bonpland, in clear weather on heights of upwards of fifteen or sixteen thousand (English) feet; and neither we, nor subsequently Boussingault, could ever recognise stars in the day-time, although the azure of the sky was so deep and dark, that with the same cyanometer of Paul of Geneva with which Saussure had read 39° on Mont Blanc, I should have found under the tropics, at elevations between 16000 and 18000 (17052 and 19184 Eng.) feet, 46° at the zenith. ([112]) Under the magnificent, ethereally pure and serene sky of Cumana, on the plain of the sea-shore, after the observation of occultations of Jupiter's satellites, I have several times with ease found the planet again with the naked eye, and seen him most distinctly whilst the sun's disk was 18° or 20° above the horizon.

This is the proper place in which to notice, at least in a cursory manner, another optical phænomenon which, among my many ascents of mountains, was only observed by me once—viz. on the 22nd of June, 1799, before sunrise, on the declivity of the Peak of Teneriffe. Being in the Malpays, 10700 (11404 Eng.) feet above the sea, I saw with the naked eye stars low down near the horizon in strange

[* Since given more correctly by Messrs. H. and A. Schlagintweit 12158 French or 12958 English feet, in their Physicalische Geographie der Alpen.—Ed.]

fluctuating movement. Luminous points rose upwards, moved sideways, and fell back to their former places. The phænomenon lasted only seven or eight minutes, and ceased long before the edge of the sun appeared above the sea horizon: it was seen equally through a telescope, and there was no doubt that the apparent movement was that of the stars themselves. (113) Did this change of place belong to the much contested question of the *lateral* refraction of rays? Does the undulation of the rising solar disk, small as it is found by measurement, present, in the lateral alteration and motion of the sun's limb, any analogy to what has been described? We know, apart from this question, that the disturbance of the sun's disk would appear larger from being near the horizon. Almost half a century later this same phænomenon has been observed, both with the naked eye and through a telescope, in exactly the same spot in the Malpays, and similarly before sunrise, by a well-informed and very attentive observer, Prince Adalbert of Prussia. I found the observation entered in his manuscript journal without his having been aware, before his return from the River Amazon, that an entirely similar appearance had been seen by me. (114) Neither on the ridges of the Andes, nor in the frequent mirage of the hot plains (Llanos) of South America, notwithstanding the excessive variety of admixture of unequally heated strata of air, could I ever find any trace of lateral refraction. As the Peak of Teneriffe is so near to us, and is often visited before sunrise by scientific travellers provided with instruments, I may hope that my renewed request for the observation of the lateral fluctuation of stars may not be without effect.

I have already drawn attention to the fact, that long before the great epoch of the invention of telescopes and

their application to celestial observation,—before therefore the memorable years 1608 and 1610,—an exceedingly important part of the astronomy of our planetary system was already established. The inherited treasures of Greek and Arabian knowledge were augmented by the careful and extensive labours of George Purbach, Regiomontanus (Johann Müller), and Bernhard Walther of Nuremberg. Their efforts were followed by the bold and comprehensive intellectual development of the Copernican system; and to this succeeded an abundant mass of exact observations by Tycho Brahe, and the acuteness in combination, and indomitable perseverance in calculation, of Kepler. Two great men, Kepler and Galileo, stand at the most important epoch which the history of practical astronomy presents,—that which separates observation with the naked eye, but with greatly improved measuring instruments, from telescopic vision. Galileo was then 44, and Kepler 37 years old; Tycho Brahe, the most exact practical astronomer of that great period, had been dead seven years. I have already remarked in the 2nd volume of Cosmos (English edition, p. 324), that Kepler's three great laws, which have made his name for ever illustrious, did not receive the praise of any one of his cotemporaries,—not even of Galileo. Discovered by a purely empirical path, but more rich in consequences to science at large than the isolated discovery of previously unseen celestial bodies, they belong entirely to the period of natural vision,—to the period of Tycho Brahe, and even to the Tychonian observations; although the printing of the "Astronomia nova, seu Physica cœlestis de Motibus Stellæ Martis" was not completed until 1609, and the third law, according to which the squares of the periodic revolutions of two

planets are in the ratio of the cubes of their mean distances, was first developed in the "Harmonice Mundi," in 1619.

The transition from natural to telescopic vision, which marks the first ten years of the seventeenth century,—and forms an epoch in astronomy, or the knowledge of celestial space, even more important than 1492 had been to the knowledge of terrestrial space,—not only enlarged indefinitely our view into creation, but also, by proposing for solution new and intricate problems, became the means of raising mathematical knowledge to a degree of brilliancy never before attained. Thus the strengthening of the organs of sense reacted upon the world of thought, leading to the invigoration of the intellectual power, and to the ennoblement of humanity. We owe to the telescope alone, within the space of two centuries and a half, the knowledge of 13 new planets, and 4 new systems of satellites (4 belonging to Jupiter, 8 to Saturn, 4, perhaps 6, to Uranus, and 1 to Neptune); of the solar spots and faculæ; of the phases of Venus; of the form and elevation of the mountains in the moon; of the winter polar zones of Mars; of the belts of Jupiter and Saturn; the ring of Saturn; the interior (planetary) comets of short periods of revolution; and of many other phænomena which, like these, escape the perception of the unassisted eye. If our solar system, which was so long limited to 6 planets and 1 satellite, has been thus enriched within the last 240 years, what is called the "heaven of the fixed stars" has, during the same period, received a still more unexpected extension. Thousands of nebulæ, clusters of stars, and double stars, have been catalogued. The variable position of the double stars which revolve around a common centre of gravity, as well as the proper motion of all the

fixed stars, show that gravitating forces prevail in those distant regions of space, as well as in the narrower sphere of the mutually perturbing orbits of the planets of our system. From the time that Morin and Gascoigne combined optical powers with measuring apparatus (which was not, however, until twenty-five or thirty years after the invention of the telescope), it has been possible to obtain more delicate and precise determinations of the alterations of place of the heavenly bodies. In this manner it has become possible to measure with the greatest precision the present position of a heavenly body, the aberration-ellipses of the fixed stars and their parallaxes, and the distances apart of the double stars, though only amounting to a few tenths of a second of arc. The astronomical knowledge of the solar system has gradually expanded into that of the system of the Universe.

We know that Galileo made his discoveries of Jupiter's satellites with a magnifying power of 7, and that he was never able to employ a higher power than 32. One hundred and seventy years afterwards, we see Sir William Herschel employ, in his investigations on the magnitude of the apparent diameters of Arcturus and $\alpha$ Lyræ, magnifying powers of 6500. From the middle of the 17th century men vied with each other in attempting telescopes of great length. Although as late as 1655 Christian Huygens discovered the first of Saturn's satellites, (Titan, the sixth in distance from the centre of the planet), with a telescope of only 12 feet, he subsequently employed in astronomical observations telescopes of 122 feet; but the three of 123, 170, and 210 feet focal distance, in the possession of the Royal Society of London, which had been made by his brother Constantine Huygens, were tried by Christian, as he himself expressly

says, (115) on terrestrial objects. Auzout, who as early as 1663 constructed colossal telescopes without tubes, and, therefore, without a solid or rigid connection between the object-glass and the eye-piece, completed an objective which, with a focal length of 300 feet, would bear a magnifying power of 600. (116) Dominic Cassini made great use of such object-glasses attached to poles, in the successive discovery, between 1671 and 1684, of the eighth, fifth, fourth, and third of the satellites of Saturn. He employed the object-glasses which Borelli, Campani, and Hartsoeker had ground: the latter were of 250 feet focal length. Those of Campani, which enjoyed the highest reputation under the reign of Louis XIV., have been often in my hands at the Paris Observatory during my long residence in that city. If we remember the faint light of the satellites of Saturn, and the difficulty of managing such apparatus, (117) which could only be moved by the aid of cords, we cannot sufficiently admire the skill and perseverance of the observer.

The advantages which were then supposed to be attainable exclusively by means of gigantic lengths, led great minds, as is often the case, to form extravagant hopes. Auzout thought it necessary to refute Hooke, who, in order to see animals in the moon, had proposed telescopes 10000 feet, or almost 2 geographical miles, in length. (118) The practical inconvenience of optical instruments of more than 100 feet focal length, gradually led to the introduction, in England especially, and through Newton himself (according to the precedents set by Mersenne and by James Gregory of Aberdeen), of the shorter reflecting instruments. Bradley's and Pound's careful comparison of 5-feet Hadleyian reflectors with the refractor already noticed of Constantine

Huygens of 123 feet focal length, proved entirely to the advantage of the former. Short's costly reflectors were now everywhere adopted, until the successful practical solution, (1759), by John Dollond, of the problem of achromatism proposed by Leonhard Euler and Klingenstierna, again turned the scale in favour of refractors. The apparently incontestable rights of priority of the mysterious Chester More Hall, of Essex (1729), were first made known to the public when John Dollond obtained a patent for his achromatic telescopes. (119)

But this victory of the refracting instruments was not of long duration: eighteen or twenty years after the publication of John Dollond's accomplishment of achromatism by a combination of crown and flint glass, new fluctuations of opinion were induced by the merited tribute of admiration paid, both in England and elsewhere, to the ever memorable labours of a German, William Herschel. The construction of his numerous 7-feet and 20-feet telescopes, to which magnifying powers of 2200 to 6000 could be successfully applied, was followed by the construction of his 40-feet reflector, by means of which were discovered, in August and September 1789, the two innermost of the satellites of Saturn,—the second, Enceladus; and soon after Mimas, the first or nearest to the ring. The discovery of the planet Uranus (1781) was made with the 7-feet telescope of Herschel. The satellites of Uranus, which have such feeble light, were first seen by him, in 1787, in his 20-feet instrument arranged for the "front view." (120) The previously unattained degree of perfection which this great man was able to impart to his reflecting telescopes, in which the light was reflected only once, led, by the unin-

terrupted labours of more than forty years, to the most important extension of all parts of physical astronomy, in the planetary system as well as in the nebulæ and double stars.

A long reign of reflectors was again followed, in the first twenty years of the nineteenth century, by a happy emulation in the construction of achromatic refractors and heliometers, moved equatorially by clock-work. For object-glasses of extraordinary size, a homogeneous flint glass, free from striæ, was supplied in Germany by the Munich establishment of Utzschneider and Fraunhofer, subsequently of Merz and Mahler; and in Switzerland and France (for Lerebours and Cauchoix), in the manufactories of Guinaud and Bontems. It is sufficient for the purpose of this historical review, to name here, as instances, the great refractors made, under Fraunhofer's superintendence, for the observatories of Dorpat and Berlin, having 9 Parisian inches free aperture, with a focal length of $13\frac{1}{3}$ (14 Engish) feet; the refractors of Merz and Mahler, in the observatories of Pulkova, and Cambridge in the United States of North America, (121) both furnished with object-glasses of 14 Parisian inches aperture, and 21 feet focal length (14·9 English inches, and 22 English feet 4·6 inches).* The heliometer of the Königsberg Observatory, which was for a long time the largest in existence, has 6 Parisian inches aperture, and has become celebrated by the memorable labours of Bessel. The short dialytic refractors, advantageous in respect of light, which Plösl, in Vienna, was the first to execute, the merits of which were recognised almost at the

* [The exact focal length of the refractor at Cambridge, U.S. is 22 English feet 6 inches.—Ed.]

same time by Rogers in England, deserve to be constructed of larger dimensions.

During the same period in which these endeavours were made,—to which I have thus referred because they have so materially influenced the enlargement of cosmical views,—mechanical improvements in measuring-instruments (zenith sectors, meridian circles, and micrometers) did not remain behind the progress made in optical instruments, and in those employed for measuring time. Amongst the many distinguished names of the present or recent times, I will mention only the following:—for measuring instruments, those of Ramsden, Troughton, Fortin, Reichenbach, Gambey, Ertel, Steinheil, Repsold, Pistor, Oertling; for chronometers and astronomical clocks — Mudge, Arnold, Emery, Earnshaw, Breguet, Jürgensen, Kessels, Winnerl, Tiede. In the valuable and extensive investigations into the distances apart and the periodic movements of double stars, which we owe to William and John Herschel, South, Struve, Bessel, and Dawes, we specially remark this proportionate and simultaneous advance in the perfection at once of sight and of measurement. Struve's classification of double stars contains, of those which are less than 1′ apart, about 100, and of those between 1′ and 2″ apart, 336,—all by frequently repeated measurements. (122)

Within the last few years, two men who, by station and circumstances, were far removed from such occupations with a view to pecuniary profit, the Earl of Rosse, at Parsonstown (fifty miles west of Dublin), and Mr. Lassell, at Starfield, near Liverpool, animated by a noble love of astronomy, have, with devoted liberality and under their own immediate direction and superintendence, accomplished the completion

of two reflecting telescopes which have raised to the highest degree the expectation of astronomers. (123) With Lassell's telescope, which has only 2 feet aperture and 20 feet focal length, there have been already discovered a satellite of Neptune and an eighth satellite of Saturn, besides the rediscovery of two satellites of Uranus. Lord Rosse's new colossal telescope has 6 feet clear aperture and 53 feet focal length. It is placed in the meridian between two piers, each 12 feet distant from the tube, and from 47 to 54 feet in height. Many nebulæ which no previous instrument could resolve, have, by this magnificent telescope, been resolved into clusters of stars, and the forms of other nebulæ have now for the first time been shown in their true outlines. The quantity of light reflected from the surface of the mirror is truly wonderful.

Morin, who, with Gascoigne, and before Picard and Auzout, first combined the telescope with measuring instruments, conceived, about 1638, the idea of observing stars telescopically in full daylight. He says himself (124) that he "was led to a discovery which may become important for the determination of longitudes at sea, not by Tycho Brahe's great labours on the positions of the fixed stars,—as, in 1582, and therefore twenty-eight years before the invention of the telescope, he compared Venus with the sun in the day-time and with the stars at night,—but merely by the simple thought that it might be possible, as with Venus so also with Arcturus and other fixed stars, once having them in the field of view of the telescope before sunrise, to continue to follow them in the heavens after sunrise." No one, he said, before him "had been able to find the fixed stars in the broad daylight." Since the establishment of great meridian telescopes by Römer in 1691, day observations of the heavenly bodies have been

frequent and highly serviceable: they are sometimes usefully applied even to the measurement of double stars. Struve (125) remarks, that with the Dorpat refractor, employing a magnifying power of 320, he had determined the smallest distances apart of exceedingly faint double stars during a twilight so bright that one could read conveniently at midnight. The Pole star has a companion of the 9th magnitude only 18″ from itself; in the Dorpat refractor Struve and Wrangel have seen this companion in the day-time, (126) as have also (once) Encke and Argelander.

The reason of the powerful effect of telescopes at a time when, by multiplied reflection, the diffused light (127) of the atmosphere is injurious, has given occasion to a variety of doubts. As an optical problem it was regarded with the most lively interest by Bessel. In his long correspondence with me he often returned to the subject, and acknowledged that he could find no solution which was entirely satisfactory to him. I think I may reckon on the thanks of my readers for the introduction in a note (128) of the views of Arago, as contained in one of the many manuscripts which I was permitted to use when at Paris. According to his ingenious explanation, high magnifying powers facilitate the finding and recognition of the fixed stars, because, without sensibly enlarging their image, they conduct a greater quantity of intense light to the eye, whilst they act according to a different law on the aerial field from which the star detaches itself. The telescope, by magnifying the distance between the illuminated particles of air, darkens the field of view, or diminishes the intensity of its illumination; and it is to be remembered that we see only by the difference between the light of the star and that of the aerial field, *i. e.* the mass of

air which surrounds it, in the telescope. The case of the simple ray of the image of a fixed star differs from that of planetary discs; the latter, under the magnifying power of the telescope, losing in intensity of light by dilatation equally with the aerial field from which they detach themselves. It is also to be noticed that high magnifying powers increase the apparent rapidity of motion in the fixed stars as well as in the planets. In instruments which are not mounted equatorially, and made to follow the movement of the heavens by means of clock-work, this circumstance may facilitate the recognition of objects in the day-time. New points on the retina are successively stimulated. Very faint shadows, as Arago has remarked elsewhere, first become visible by being put in motion.

Under the serene sky of the tropics in the driest season of the year, I have often been able to find the pale disc of Jupiter, in a Dollond's telescope, with the low magnifying power of 95, when the sun was already 15° or 18° above the horizon. The faintness of the light of Jupiter and Saturn seen in the day-time in the large Berlin refractor, and contrasted with the brighter, though equally reflected, light of the planets nearer to the sun, Mercury and Venus, has repeatedly surprised Dr. Galle. Occultations of Jupiter's satellites have sometimes been observed in the day-time with powerful telescopes (by Flaugergues, 1792; and Struve, 1820). Argelander, at Bonn (7th December, 1849), saw very clearly three of Jupiter's satellites a quarter of an hour after sunrise with a 5-feet Fraunhofer. He could not recognise the fourth satellite. His assistant, Herr Schmidt, saw still later the emersion from behind the dark limb of the moon of all the satellites, including the fourth, in the

8-feet heliometer. The determination of the limits of telescopic visibility of small stars during daylight, in different climates and at different elevations above the level of the sea, has both an optical and a meteorological interest.

Among the phænomena belonging to natural and telescopic vision which are remarkable in themselves, and of which the causes are much contested, is the nocturnal sparkling (twinkling or scintillation) of the stars. According to Arago,([129]) there are two things to be essentially distinguished in the scintillation: 1. alteration in the intensity of the light by a sudden decrease, amounting even to extinction, and rekindling; 2. alteration of colour. Both alterations are even stronger in reality than they appear to the naked eye; for when the several points of the retina are once excited, they retain the impression of light which they have received; so that the disappearance of the star, its obscuration, and its change of colour, are not felt by us in their full measure. Still more striking is the phænomenon of scintillation seen through a telescope, if the latter is shaken. Fresh and fresh points of the retina are excited, and there appear coloured and often interrupted circles. In an atmosphere composed of constantly varying strata of different temperature, moisture, and density, the principle of interference explains how, after a momentary coloured flash, there follows an equally momentary disappearance or obscuration. The undulation theory teaches in general that two rays of light (two systems of waves) proceeding from one source (one centre of vibration) by the inequality of their paths destroy each other; that the light of one ray, added to that of the other ray, produces darkness. When one sys-

tem of waves is so far behind the other as amounts to an uneven number of semi-undulations, the two systems of waves strive to impart to the same molecule of ether, at the same instant, equal but opposite velocities; so that the effect of their union is the repose of the molecule, or darkness. In some cases it is rather the refrangibility of the different atmospheric strata traversed by the rays of light, than the different length of their paths, which performs the principal part in the phænomenon.(130)

The degree of scintillation is strikingly different in different fixed stars; not dependent solely on their altitude or their apparent magnitudes, but also, it would seem, on the nature of their particular light. Some, for example α Lyræ, twinkle less than Arcturus and Procyon. The absence of scintillation in the planets with the largest discs is to be ascribed to compensation, and to the mixture of the colours proceeding from different points of the disc. The disc is to be regarded as an aggregation of stars, which mutually restore the light neutralised by interference, and recombine the coloured rays into white light. Thus traces of scintillation are most rare in Jupiter and Saturn, but are seen in Mercury and Venus, whose diameters diminish to 4″·4 and 9″·5. The diameter of Mars, at the time of conjunction, may be as small as 3″·3. In the clear cold winter nights of the temperate zone, the scintillation of the stars enhances the impression of the lustre of the starry heavens from the circumstance that, as we see stars of the 6th and 7th magnitudes shine forth suddenly here and there, we are led to imagine that we perceive more shining points than the unassisted eye can really distinguish. Hence arises the popular surprise at the few thousands of stars noted in

accurate catalogues as visible to the naked eye. That the trembling light of the fixed stars distinguishes them from the planets, was early known to the Grecian astronomers; but Aristotle, in accordance with the emanation and tangential theory of vision to which he adhered, singularly enough ascribed the trembling and twinkling of the fixed stars merely to an effort or straining of the eye. "The fixed stars," said he,([131]) "sparkle, but the planets do not: for the planets are near, so that the sight is able to reach them; but in the fixed stars (πρὸς δὲ τους μένοντας) the eye, by reason of the distance and the effort, falls into a tremulous movement."

In Galileo's time, between 1572 and 1604,—in an epoch of great events in cosmical space, and when three new stars([132]), brighter than stars of the first magnitude, appeared suddenly, and one of them, in Cygnus, continued to shine for twenty-one years,—Kepler's attention was particularly drawn to scintillation as the probable criterion of a non-planetary body; but the state of optics at that period did not permit him to rise above the ordinary ideas of vapours in motion. ([133]) Also, among the newly-appeared stars mentioned in the Chinese annals, according to the great collection of Ma-tuan-lin, the strong degree of scintillation is sometimes noticed.

In and near the tropical zone, from the more uniform character of the atmospheric strata, the comparative or entire absence of scintillation in the fixed stars to within twelve or fifteen degrees of the horizon, gives to the vault of heaven a peculiar character of repose and tranquil brilliancy. In several of my descriptions of nature, I have spoken of this characteristic of the tropics, which had not

escaped the observation of La Condamine and Bouguer in the Peruvian plains, and of Garcin (134) in Arabia, India, and on the coasts of the Persian Gulf, near Bender Abassi.

As the aspect of the starry heavens at the season of perpetually clear and perfectly cloudless tropical nights had for me a peculiar charm, I took the pains of always noting in my journals the altitude above the horizon at which the scintillation ceased with different hygrometrical readings. Cumana, and the rainless part of the Peruvian sea-coast, before the season of Garua or fog, were particularly suited for such observations. According to the mean results of my observations, the larger fixed stars would appear for the most part to scintillate only when below 10° or 12° from the horizon. At greater altitudes they shed a mild and planetary light. The difference is best recognised by following the same star in its gradual ascent or descent, measuring at the same time its angle of altitude, or calculating it, if the latitude of the place and the time be known. Sometimes, in equally clear and equally calm nights, the region of scintillation extends to 20° and even 25° of altitude; yet there could hardly ever be traced any connection between these differences, and the state of the thermometer and hygrometer as observed in the lowest, and only accessible, atmospheric stratum. I have seen in successive nights, after considerable scintillation of stars between 60° and 70° high, with Saussure's hair hygrometer at 85°, the scintillation cease entirely at 15° above the horizon, although the humidity of the air had so much increased that the hygrometer had advanced to 93°. It is not the quantity of aqueous vapour which the atmosphere holds in solution, but the unequal distribution of vapour in the superimposed strata,

and the upper currents of cold and warm air, not perceptible in the lower regions, which modify the intricate compensatory movement of the interferences of the luminous rays. The presence of a very thin orange-coloured mist, which tinged the sky a short time before earthquake shocks, increased the scintillation of the stars at high altitudes in a striking manner. All these remarks apply to the perfectly clear, cloudless, and rainless season of the tropical zone 10 or 12 degrees north and south of the equator. The changes which take place in the phænomena of the light of the stars at the commencement of the rainy season, during the passage of the sun through the zenith, depend on very general and almost tempestuous meteorological causes. The sudden slackening of the north-east trade wind, and the interruption of the regular upper currents from the equator to the poles, and of the lower currents from the poles to the equator, produce the formation of clouds, and the daily occurrence, at certain hours, of thunder and heavy rain. I have remarked in several successive years, in places where the scintillation of stars is at other times a rare occurrence, that the approach of the rainy season is announced many days beforehand by the tremulous light of stars high in the heavens. Sheet lightning, and single flashes in the distant horizon, without visible cloud, or in narrow perpendicularly rising columns of cloud, are accompanying signs. In several of my works I have tried to describe these changes in the physiognomy of the heavens, which are the characteristic precursors of the rainy season.

On the subject of the velocity of light, and the probability that it requires a certain time for its propagation, we find

the earliest view expressed by Francis Bacon, in the second book of the Novum Organum. He speaks of the time required by a ray of light to traverse the immensity of space, and throws out the question whether the stars still exist which we now see sparkle.(136) One is astonished at finding so happy a conjecture in a work whose celebrated author was so far below some of his cotemporaries in mathematical, astronomical, and physical knowledge. The velocity of the reflected solar light was measured by Römer (November 1675) by comparison of the times of occultation of Jupiter's satellites; and the velocity of the direct light of the fixed stars by Bradley's great discovery of the aberration of light (made in the autumn of 1727),—that demonstration to our senses of the earth's movement of translation in its orbit; viz. of the truth of the Copernican system. In very recent times a third method of measurement has been proposed by Arago, by the phænomena of the light of a variable star; for example, Algol in Perseus. (137) We have to add to these astronomical methods a terrestrial measurement, which has very recently been executed with great ingenuity and success by M. Fizeau, in the neighbourhood of Paris. It recals to recollection an attempt of Galileo's with two lanterns, which did not lead to any result.

From Römer's first observations of Jupiter's satellites, Horrebow and Du Hamel estimated the time occupied in the passage of light from the sun to the earth, at their mean distance apart, at 14′ 7″; Cassini, at 14′ 10″; Newton(138), which is very striking, much nearer to the truth, at 7′ 30″. Delambre,(139) by taking into account, among the observations of his time, only those of the first satellite, found 8′ 13″·2. Encke has very justly remarked how

important it would be, with the certainty of obtaining the more accordant results which the present perfection of telescopes would afford, to undertake a series of occultations of Jupiter's satellites, for the express purpose of deducing the velocity of light.

From Bradley's observations of aberration, recently rediscovered by Rigaud of Oxford, there follows, according to the investigation of Dr. Busch ([140]) of Königsberg, for the passage of light from the sun to the earth, 8′ 12″·14; for the velocity of the light of the stars 167976 geographical miles in a second; and for the constant of aberration, 20″·2116 : but, from the more recent aberration-observations of Struve, made for eighteen months with the large transit instrument at Pulkova,([141]) it appears that the first of these numbers must be considerably increased. The result of Struve's great investigation is 8′ 17″·78; whence, with the aberration-constant, 20″.4451, with Encke's correction of the sun's parallax made in 1835, and with the value of the earth's semi-diameter given by him in the Jahrbuch for 1852, we have for the velocity of light 166196 geographical miles in a second. The probable error of the velocity scarcely amounts to eight geographical miles. Struve's result for the time which light requires to reach the earth from the sun differs $\frac{1}{110}$ from that of Delambre (8′ 13″·2), which latter was employed by Bessel in the Tabulæ Regiomontanæ, and has been used hitherto in the Berlin Astronomical Almanack. The discussion of this subject cannot be regarded as completely terminated; but the earlier entertained supposition, that the velocity of the light of the Pole-star was less than that of its companion in the ratio of 133 : 134, remains subject to great doubts.

A physicist distinguished for his knowledge as well as for his great delicacy in experimenting, M. Fizeau, has succeeded in executing a terrestrial measurement of the velocity of light, by means of an ingeniously devised apparatus, in which the artificial star-like light of oxygen and hydrogen is returned to the point from whence it came, by a mirror placed at a distance of 8633 mètres (28324 English feet), between Suresne and La Butte Montmartre. A disc, furnished with 720 teeth, which made 12·6 revolutions in a second, alternately stopped the ray of light, and allowed it to pass freely between the teeth of the limb. From the indications of a counter (compteur) it was inferred, that the artificial light traversed 17266 mètres (56648 Eng. feet), or twice the distance between the stations, in $\frac{1}{18000}$ of a second of time; whence there results a velocity of 167528 geographical miles in a second. (142) This result comes nearest to that of Delambre derived from Jupiter's satellites, which is 167976 geographical miles in a second.

Direct observations, and ingenious considerations on the absence of any alteration of colour during the change of light of variable stars, (a subject to which I shall presently return), have led Arago to the conclusion that, (in the language of the undulatory theory), rays of light which have different colours, and therefore very different lengths and rapidities of transverse vibration, move through space with equal velocities; but that in the interior of the different bodies through which the coloured rays pass, their rates of propagation and their refractions are different. (143) Arago's observations have shown that in the prism the refraction is not altered by the relation which the velocity of light bears to that of the Earth's motion. All the measurements accord in the

result, that the light of the stars towards which the Earth is advancing has the same index of refraction, as the light of the stars from which the Earth is receding. Speaking in the language of the emission hypothesis, the celebrated observer we have just named said, that bodies send forth rays of all velocities, but that among these different velocities there is only one which can awaken the sensation of light. (144)

If we compare the velocities of solar, sidereal, and terrestrial light, which all comport themselves exactly in the same manner in the prism, with the velocity of the current of friction-electricity, we are inclined to assign to the latter, according to the experiments devised with admirable ingenuity by Wheatstone, a velocity superior to the former in the ratio of at least 3 to 2. According to the lowest results of Wheatstone's optical rotating apparatus, the electric current traverses 288000 English statute miles, or 250000 geographical miles, in a second. (145) If, then, we reckon with Struve for sidereal light in the aberration-observations 166196 geographical miles in a second, we get a difference of 83804 geographical miles in a second for the greater velocity of the electric current.

This result appears to contradict the previously mentioned view of William Herschel, which regarded the light of the sun and of the fixed stars as perhaps the effect of an electro-magnetic process,—a perpetual Aurora. I say appears to contradict; for it cannot be deemed impossible that, in the different luminous bodies of space, there may be several magneto-electric processes very different in kind, and in which the light produced by the process may have a different rate of propagation. To this possible conjecture must be added the uncertainty of the numerical result obtained with

Wheatstone's apparatus, which result he himself regards as "not sufficiently established, and as requiring fresh confirmation" in order to be compared satisfactorily with the deductions from aberration- and satellite- observations.

Later experiments made by Walker in the United States of North America on the velocity of the propagation of electricity, on the occasion of his telegraphic determinations of the longitudes of Washington, Philadelphia, New York, and Cambridge, have excited a lively interest in the minds of physical enquirers. According to Steinheil's description of these experiments, the astronomical clock of the Observatory at Philadelphia was connected with Morse's writing apparatus on the line of telegraph in such manner, that the clock's march noted itself by points on the endless strip of paper of the apparatus. The electric telegraph carries each of these points instantaneously to the other stations, and gives them the Philadelphia time by similar points on their moving strips of paper. Arbitrary signals, or the instant of the passage of a star, may be noted in the same manner by the observer, by merely touching or pressing an index with his finger. The material advantage of this American method consists, as Steinheil expresses it, "in its making the determination of time independent of the connection of the two senses, sight and hearing; as the clock's march notes itself, and the instant of the star's passage is given direct (to within a mean error of the 70th part of a second, as Walker states) by the movement of the observer's finger. A constant difference between the compared clock-marks of Philadelphia and Cambridge is produced by the time which the electric current requires to traverse twice the closed circuit between the two stations."

Measurements made with conductors 1050 Eng. statute miles, or 968 geographical miles, in length, gave, from 18 equations of condition, the rate of propagation of the hydro-galvanic current at only 18700 statute or 16240 geographical miles in a second; (146) *i. e.* fifteen times slower than the electric current in Wheatstone's rotating disc apparatus! As in Walker's remarkable experiments two wires were not used, but half the conduction, according to the common expression, took place through the moist body of the earth, it might seem a justifiable supposition that the velocity of the propagation of electricity is dependent on the nature as well as on the dimensions (147) of the medium. In the voltaic circuit bad conductors become more heated than good conductors, and electric discharges are very variously complicated phenomena, as appears by the latest experiments of Riess. (148) The now prevailing views respecting what is commonly called "connection through the Earth" are opposed to the view of linear molecular conduction between the two ends of the wire, and to the conjectures of impediments to conduction, and of accumulation and discharges in a current; as that which was once regarded as intermediate conduction in the Earth is now supposed to belong only to an equalisation or to a restoration of electric tension.

Although, according to the present limits of exactness in this kind of observation, it is probable that the aberration-constant, and therefore the velocity of light, of all the fixed stars, is the same, yet the possibility has more than once been spoken of, that there may be luminous bodies in space whose light does not reach us because, from their enormous mass, gravitation constrains the luminous particles to return. The emission theory gives to such fancies a scientific

form: (149) I only allude to them here, because I shall subsequently have to notice certain peculiarities of motion ascribed to the star Procyon, which appear to point to a perturbation by dark bodies. It is the object of this part of my work to touch on matters which, during the time in which it has been in progress, have influenced the direction which science has pursued, and thus to mark the individual character of the epoch in regard to the study of Nature, whether in the sidereal or the telluric sphere.

The photometrical relations, or relative brightness, of the self-luminous bodies which fill space, have formed a subject of scientific observation and estimation for more than two thousand years. The description of the starry heavens included not only the determinations of place, the measurement of the angular distances of the heavenly bodies, and of their paths relatively to the apparent course of the sun and the diurnal movement of the celestial vault, but also the relative intensity of light in different stars. It was no doubt the subject which earliest drew the attention of men; single stars received names before they were combined with others into imaginary groups or constellations. Among the small savage tribes inhabiting the densely wooded districts of the Upper Orinoco and Atabapo, in places where the impenetrable thickness of the forest usually obliged me to observe only high culminating stars for determinations of latitude, I often found single individuals, especially old men, who gave particular names to Canopus, Achernar, the feet of the Centaur, and the principal star in the Southern Cross. Supposing the list of constellations which we have under the name of the Catasterisms of Eratosthenes really to possess the

high antiquity so long ascribed to it, (between Autolycus of Pitane and Timocharis, almost a century and a half, therefore, before Hipparchus), we should possess in the astronomy of the Greeks an indication of the time when the fixed stars were not yet classed according to their relative brightness. In the Catasterisms, in speaking of the stars which make up a constellation, there is often a notice of the number of those which are "brightest" or "largest" among them, while others are said to be dark or little noticeable, (150) but nothing is said of the stars in one constellation relatively to those in another. According to Bernhardy, Baehr, and Letronne, the Catasterisms are two centuries more modern than the Catalogue of Hipparchus, and are a mere compilation made without much care, an extract from the Poeticum astronomicum ascribed to Julius Hyginus, if not from the Ἑρμῆς of the ancient Eratosthenes. The Catalogue of Hipparchus, which we possess in the form given to it in the Almagest, contains the first and important determination of the classes of magnitude (degrees of brightness) of 1022 stars, or about 1-5th of all the stars visible to the naked eye in the whole heavens between the 1st and 6th magnitudes inclusive. Whether the estimations are exclusively Hipparchus's own, or whether they do not rather belong in part to the observations of Timocharis or Aristyllus which Hipparchus so often used, remains uncertain.

This work formed the foundation on which the Arabians and the whole of the middle ages continued to build; and even the habit which has been carried on into the 19th century, of limiting the number of stars of the 1st magnitude to 15 (Mädler counts 18, and Rümker, after a careful examination of the southern heavens, above 20), is derived from

the classification of the Almagest at the close of the Table of Stars in the 8th book. Ptolemy, with reference to unassisted vision, called all stars "dark" which were fainter than his 8th class, of which class singularly enough he gives only 49, almost equally distributed in the two hemispheres. Considering that the table includes about a fifth part of the stars visible to the naked eye, it ought, according to Argelander's investigations, to have given 640 stars of the 6th magnitude. The nebulous stars (νεφελοειδεῖς) of Ptolemy, and of the Catasterisms of the Pseudo-Erastosthenes, are mostly small clusters of stars (151) which, in the purer air of southern skies, appear as nebulæ. I rest this conjecture more particularly on the mention of a nebula in the right hand of Perseus. Galileo, to whom, as well as to the Greek and Arabian astronomers, the nebula in Andromeda, although visible to the naked eye, was unknown, said, in the Nuncius sidereus, that "stellæ nebulosæ" are no other than clusters of stars, which as "areolæ sparsim per æthera fulgent."(152) The expression "order of magnitude" (τῶν μεγάλων ταξις), although referring only to brilliancy, yet led, as early as the 9th century, to hypotheses respecting the diameters of stars of different degrees of brightness; (153) as if the intensity of the light did not depend on the distance, the volume, the mass, and the peculiar nature or character of the surface of the body, as more or less favourable to the luminous process or production of light.

At the time of the Mogul Power in the 15th century, when, under Ulugh Beig, the descendant of Timour, astronomy flourished in the highest degree at Samarcand, photometric determinations received such an impulse, that each of the six classes or orders of magnitude of Hipparchus and

Ptolemy were divided into three subdivisions; distinguishing, for example, small, middling, and large, of the second magnitude; reminding us of the attempts of Struve and Argelander, in our own day, to introduce decimal gradations.(154) In the tables of Ulugh Beig, this photometric advance, or more exact determination of different degrees of light, is ascribed to Abdurrahman Sufi, who had published a work specially "on the knowledge of the fixed," or fixed stars, and who first noticed the existence of one of the magellanic clouds under the name of the "White Ox." Since the introduction of telescopic vision, and its gradual improvement, estimations of successive gradations of light have extended far beyond six classes or magnitudes. The desire of comparing with the light of other stars the newly-appeared stars in Cygnus and Ophiuchus, (the first of which continued to shine for 21 years), at successive stages of their increasing and decreasing light, gave a stimulus to photometric considerations. The so-called "dark" stars of Ptolemy, or those below the 6th magnitude, received numerical denominations corresponding to the relative intensity of their light. "Astronomers," says Sir John Herschel, "who are accustomed to the use of powerful space-penetrating telescopes, pursue the descending gradations of light from the 8th down to the 16th magnitude." (155) But with such faint degrees of light, the denominations of the different classes of magnitude sometimes become very uncertain; and Struve occasionally reckons as belonging to the 12th or 13th magnitude stars which John Herschel calls of the 18th or even 20th.

This is not the place for examining in a critical manner the very different methods which have been applied to photometric determinations, during the last century and a half,

from Auzout and Huygens to Bouguer and Lambert; and from William Herschel, Rumford, and Wollaston, to Steinheil and John Herschel. It is sufficient, according to the object of this work, to notice them in a brief and general manner. They include comparison with the shadows of artificial lights differing in number and distance; diaphragms; plane glasses of different thicknesses and colours; artificial stars formed by reflection on glass globes; two 7 feet telescopes so placed that the observer could pass from one to the other in scarcely more than a second of time; reflecting instruments, in which two stars which were to be compared could be seen at once, after the telescope had been so arranged that the star which was seen direct had given two images of equal intensity;(156) apparatuses with a mirror adapted to the objective, and with shades, the degree of intensity being measurable on a ring; telescopes with divided object-glasses, each half of which received the star's light through a prism; and astrometers,(157) in which the image of the Moon, or of Jupiter, is reflected by a prism, and this image is concentrated by a lens, at different distances, into a brighter or fainter star. The distinguished astronomer, who in modern times has most zealously pursued in both hemispheres the numerical determination of the intensity of light in different stars, Sir John Herschel, owns, notwithstanding what he has himself accomplished, that the practical application of exact photometric methods must still be regarded as a "desideratum in astronomy," and that "photometry or the measurement of light is still in its infancy." The increasing interest taken in variable stars, and a new cosmical event in the extraordinary augmentation of light in a star of the ship

Argo, in 1837, have made the want of better photometric processes more than ever felt.

It is material to distinguish between the mere successive arrangement of stars in the order of their brilliancy, but without numerical estimations of the intensity of light, (the Scientific Manual for Naval Officers, published by the British Admiralty, contains such a list), and classifications with numbers appended expressing the intensity of light, either under the form of so-called relations of magnitude, or by the more hazardous assignment of the quantities of radiated light. (158) The first numerical series, founded on estimations with the naked eye, but progressively improved by a careful revision of the materials, (159) probably deserves, in the present very imperfect state of photometric apparatus, the preference among the different approximate methods; although the exactness of the estimations is no doubt impaired by differences in the individual powers and habits of different observers,—the clearness of the atmosphere,—the different altitudes of the stars which are to be compared, and which can only be so by means of many intermediate links,—and, above all, by inequalities of colour. Very bright stars of the 1st magnitude, Sirius and Canopus, $\alpha$ Centauri and Achernar, Deneb and $\alpha$ Lyræ, though they have all white light, are much more difficult to compare with each other by estimation with the naked eye, than are stars of fainter light,—as, for example, those below the 6th and 7th magnitudes. But the difficulty is still greater with stars of very intense light, when yellow stars like Procyon, Capella, or Atair, are to be compared with red ones like Aldebaran, Arcturus, and Betelgeuze. (160)

Sir John Herschel, by means of a photometric comparison

of the Moon with the double star $\alpha$ Centauri in the southern heavens, the third in brightness of all the fixed stars, has attempted to determine the ratio between the intensity of the solar light, and the light of a star of the 1st magnitude; fulfilling thereby (as had been earlier done by Wollaston) a wish expressed by John Michell (161) in 1767. From the mean of 11 measurements made with a prismatic apparatus, Sir John Herschel found the full moon 27408 times brighter than $\alpha$ Centauri. Now the light of the Sun is, according to Wollaston, (162) 801072 times greater than that of the full moon; whence it follows that the light which the Sun sends to us is to that which we receive from $\alpha$ Centauri about as 22000 millions to 1. Hence it would follow with great probability that, if we take into account the distance of $\alpha$ Centauri according to its parallax, its inherent (absolute) light would be 2·3 times as great as that of our Sun. Wollaston found the brightness of Sirius 20000 million times less than that of the Sun; and according to what is now supposed to be known in respect to the parallax of Sirius, (0″·230), its actual (absolute) light would be 63 times greater than that of the Sun. (163) Our Sun would thus be, in regard to the intensity of its light, one of the fainter of the fixed stars. Sir John Herschel estimates the light of Sirius as equal to that of nearly two hundred stars of the 6th magnitude. As from analogy with what we already know it is very probable that all cosmical bodies change their place in space, as well as the strength of their light,—though it may be only in very long and unmeasured periods of time,—and remembering the dependence of all organic life on temperature and the strength of the Sun's light, the improvement of photometry appears deserving

of being regarded as a great and serious object of scientific investigation. This improvement can alone render it possible to leave to future generations numerical determinations respecting the light of the heavenly bodies. Many geological phænomena which connect themselves with the thermic state of our atmosphere, and relate to the former distribution of plants and animals on the surface of our globe, may be elucidated thereby. More than half a century ago such considerations had not escaped the great investigator William Herschel, who before the close connection between electricity and magnetism had been discovered, compared the ever luminous cloud-envelopes of the solar orb, to the Polar Light of the terrestrial globe. (164)

Arago recognised in the complementary condition of coloured rings seen by transmission and reflection, the most promising means of a direct measure of the intensity of light. I give in a note (165) in my friend's own words a statement of his photometric method, to which he has also added the optical principle on which his cyanometer rests.

The so-called relative magnitudes of the fixed stars now given in our Catalogues and Star Maps are partly belonging to the same epoch, and partly include alterations of light belonging to different epochs. We cannot, however, as was long assumed, take as a safe criterion of such changes, the succession of the letters of the alphabet appended to the stars in the Uranometria Bayeri, which has been in such extensive use since the beginning of the 17th century. Argelander has shewn that we cannot infer relative brightness from alphabetical order, and that Bayer allowed himself to be guided in the choice of letters by the shape and direction of the constellations. (166)

# III.

## NUMBER, DISTRIBUTION, AND COLOUR OF THE FIXED STARS—CLUSTERS OF STARS.—MILKY WAY, IN WHICH A FEW NEBULÆ ARE INTERSPERSED.

I HAVE already alluded, in the first section of this fragmentary Astrognosy, to a consideration which was first proposed by Olbers. ([167]) If the whole vault of heaven were covered with a countless succession of starry strata one behind another, forming an unbroken starry canopy, then, supposing also their light to be unenfeebled in traversing space, no single constellation could be recognised amidst the universal brightness. The Moon would be seen as a dark disk, and the Sun would be known only by his spots. I have been forcibly reminded of a state of the heavens which, totally opposite in its cause, would be equally disadvantageous to human knowledge, by what takes place during a portion of the year on the Peruvian plain between the shores of the Pacific and the chain of the Andes. A thick mist covers the sky for several months during the season called "el tiempo de la garua." No planet, not one even of the brightest stars of the Southern Hemisphere, neither Canopus, nor the Southern Cross, nor the two bright stars of the Centaur, are visible. Often one can hardly conjecture the place of the Moon. If, occasion-

ally during the day-time it is possible to distinguish the outline of the Sun's disk, it appears rayless; shorn of its beams, as if viewed through a coloured glass; usually of a yellowish red or orange colour; now and then white, or most rarely bluish green. Navigators, driven by the cold oceanic current flowing from south to north, and unable to obtain observations for latitude, sail past the harbour which they desire to enter. It is only, as I have shown elsewhere, by the use of the dipping needle ([168]) that, thanks to the direction of the magnetic lines in that part of the globe, they may be enabled to avoid error.

Bouguer and his coadjutor, Don Jorge Juan, complained long before me of the "unastronomical sky of Peru." A grave consideration is suggested by the character of this atmospheric stratum, which is so unfavourable to the transmission of light, and so unfitted for electric discharges, that thunder and lightning are unknown there, and which veils the plains in constant mist, while above, the Cordilleras raise aloft, free and unclouded, their elevated plains and snowy summits. According to the conjectures which modern geology leads us to form respecting the ancient history of our atmosphere, its primitive state, in respect to composition and density, must have been but little favourable to the passage of light. If, then, we think of the many processes which may have been in operation in the early state of the crust of the globe, in the separation of solid, liquid, and gaseous substances, we are impressed with a view of how possible it must have been, that we should have been subjected to conditions and circumstances very different from those which we actually enjoy. We might have been surrounded by an untransparent atmosphere, which, while but

little unfavourable to the growth of several kinds of vegetation, would have veiled from us the whole starry firmament. Man's investigating spirit would then have been deprived of all knowledge of the structure of the Universe. Creation would have appeared to us limited either solely to our own Globe, or comprising, at the utmost, the Sun and Moon besides. Universal space would have seemed to us to be occupied only by a triple star, consisting of Sun, Earth, and Moon. Deprived of a great, and, indeed, of the most sublime part of his ideas of the Cosmos, Man would have been without the inducements, which have unceasingly stimulated him during thousands of years to the solution of difficult and important problems, and have exercised so beneficial an influence on the most brilliant advances in the higher departments of mathematics. Before proceeding to the enumeration of that which we have already attained, it may be permitted to us thus briefly to glance at a danger from which we have been preserved, and which might have opposed impassable physical barriers to the full intellectual development of our race.

In the consideration of the number of heavenly bodies which fill space, three questions are to be distinguished:—How many fixed stars are seen with the naked eye? how many of these have been progressively catalogued, together with the determination of their places (in latitude and longitude, or in declination and right ascension)? and what is the number of stars, from the 1st to the 9th and 10th magnitudes, which have been seen through telescopes in all parts of the heavens? These three questions admit of being answered, approximately at least, according to the materials already supplied by observation. Of a different class are

the conjectures which, founded on the "star-gaugings" of particular parts of the Milky Way, touch the theoretical solution of the question—How many stars would be distinguished over the whole heavens by Herschel's 20-foot telescope, comprehending all those stars whose light is believed(169) to have required 2000 years to reach the Earth?

The numerical data which I here publish on this subject are chiefly taken from the final results obtained by my highly esteemed friend Argelander, Director of the Astronomical Observatory at Bonn. The author of the "Review of the Northern Heavens" has carefully examined for me afresh, at my request, the data supplied by Star-catalogues up to the present time. In the lowest class of stars visible to the naked eye some uncertainty is occasioned by the difference of estimation caused by organic differences in individual observers, stars between the 6th and 7th magnitudes being found among those of the 6th magnitude. By a variety of combinations we obtain, as a mean number, from 5000 to 5800 as the number of stars visible to the unassisted eye, throughout the entire heavens. The distribution of the fixed stars in descending magnitudes down to the 9th, is given by Argelander (170) approximately as follows:—

| 1st magnitude. | 2nd magnitude. | 3rd magnitude. | 4th magnitude. | 5th magnitude. |
|---|---|---|---|---|
| 20 | 65 | 190 | 425 | 1100 |

| 6th magnitude. | 7th magnitude. | 8th magnitude. | 9th magnitude. |
|---|---|---|---|
| 3200 | 13000 | 40000 | 142000 |

The number of stars which can be clearly distinguished by the naked eye (4022 above the horizon of Berlin, 4638 above that of Alexandria), appears at first sight astonishingly

small.(171) If we take the mean semi-diameter of the moon at 15′ 33″.5., 195291 surfaces of the full moon would cover the whole heavens. Assuming an equable distribution, and taking the entire number of stars of all classes from the 1st to the 9th in round numbers at 200000, we should have about one such star for every full-moon surface. This result explains to us why in any given latitude stars visible to the naked eye are not oftener occulted by the moon. If the calculation of occultations was extended to stars of the 9th magnitude, there would be, according to Galle, on the average an occultation every $44\frac{1}{2}$ minutes; as in this time the moon passes over a fresh piece of the heavens equal to its own area. Pliny (who was certainly acquainted with Hipparchus's list of stars, and who calls it a bold undertaking in Hipparchus to seek to "bequeath to posterity the starry heavens as an inheritance") reckoned in the fine sky of Italy 1600 stars,(172) having descended in this estimation to stars of the 5th magnitude; half a century later, Ptolemy recorded only 1025 stars, down to the 6th magnitude.

Since the fixed stars ceased to be distinguished merely in respect to the constellations to which they belonged, but have been tabulated according to their relations to the great circles of the Equator or the Ecliptic, and therefore according to determinations of their places, the number as well as the exactness of such entries have constantly increased with the progress of science and the increased perfection of instruments. No catalogue has come down to us from Timocharis and Aristyllus (283 B. C.); but even though their observations, as Hipparchus says in his fragments "upon the length of the year," quoted in the 7th book of the Almagest (cap. 3,

p. 15, Halma), were very incomplete (πάνυ ὁλοσχερῶς), yet there can be no doubt that they both determined the declination of many stars, and that these determinations preceded by almost a century and a half Hipparchus's Table of Fixed Stars. It is known (although we have only Pliny's statement of the fact) that Hipparchus was stimulated by the appearance of a new star to pass the heavens in review and to determine the places of the stars. This statement has, however, more than once been regarded as merely the echo of a tale invented after the period to which it relates; ([173]) and it is certainly remarkable that Ptolemy does not allude to it in the slightest degree. It is, however, incontestably true that it was the sudden appearance of a bright star in Cassiopeia (November, 1572) that occasioned Tycho Brahe to undertake his great star-catalogue. According to an ingenious conjecture of Sir John Herschel,([174]) a star which appeared in the constellation of Scorpio in the month of July, 134 years before our Era (according to the Chinese annals under the reign of Wou-ti, of the Han Dynasty), may very well be the same which Pliny mentions. Its appearance falls six years before the epoch at which (according to Ideler's researches) Hipparchus prepared his catalogue. Edouard Biot, of whom science has been too early deprived, discovered the notice of this cosmical event in the celebrated collection of Ma-tuan-lin, which contains all the appearances of comets and unusual stars between the years 613 B.C., and A.D. 1222.

The tripartite didactic poem of Aratus,([175]) to which we owe the only writing of Hipparchus which has come down to us, belongs to about the period of Eratosthenes, Timocharis, and Aristyllus. The astronomical (not meteorological)

part of the poem is founded on the description of the heavens given by Eudoxus of Cnidos. The star-table of Hipparchus has unhappily not been preserved to us: according to Ideler (176) it probably formed the principal part of the treatise, cited by Suidas, on the arrangement of the heaven of the fixed stars and the other heavenly bodies, and contained 1080 positions for the year 128 before our Era. In Hipparchus's Commentary, all the positions, determined probably by equatorial armillæ rather than by the astrolabe, are referred to the equator by right ascension and declination; in the star-table of Ptolemy, which is supposed to be altogether imitated from Hipparchus, and which, including five so-called nebulæ, contains 1025 stars, they are referred to the Ecliptic (177) by assigned longitudes and latitudes. If we compare the number of fixed stars in the Almagest, (ed. Halma, T. ii. p. 83),

| 1st mag. | 2nd mag. | 3rd mag. | 4th mag. | 5th mag. | 6th mag. |
|---|---|---|---|---|---|
| 15 | 45 | 208 | 474 | 217 | 49 |

with the numbers of Argelander in a previous page, we see (with a neglect of stars of the 5th and 6th magnitudes which was to be expected,) a remarkable fulness in the 3rd and 4th magnitudes. The indeterminateness of estimations of the degree of light in ancient and modern times does, indeed, throw great uncertainty on every direct comparison.

If the catalogue of the fixed stars, which bears the name of Ptolemy, only comprises a fourth part of the stars visible to the naked eye at Rhodes and Alexandria,—and if, from the erroneous reduction for precession, it gives positions as if they had been determined in the year 63 of our Era,—we have in the next sixteen centuries only three original, and

for their epoch complete, star-catalogues: that of Ulugh Beig (1437), of Tycho Brahe (1600), and of Hevelius (1660). In the short intervals of repose which intervened between the devastations of war and wild intestine revolutions, practical astronomy flourished among the Arabians, Persians, and Moguls, from the middle of the 9th to that of the 15th centuries,—from Al-Mamun, son of the great Harun Al-Raschid, to the Timuride, Mohammed Teraghi Ulugh Beig, son of the Shah Rokh,—in a degree never before witnessed. The astronomical tables of Ebn-Junis (1007), called the Hakemite Tables in honour of the Fatimite Caliph Aziz Ben-Hakem Biamrilla, testify,—as do also the Ilkhanic Tables ([178]) of Nassir-Eddin Tusi, the builder of the great observatory of Meragha, not far from Tauris (1259),—to the more advanced knowledge of the planetary movements, the improvement of measuring instruments, and the multiplication of methods differing from those of Ptolemy, and superior to them in exactness. In addition to Clepsydras, Pendulum oscillations ([179]) now began to be used as a measure of time.

The Arabians have the great merit of having shewn how by the intercomparison of observations and tables the latter might be greatly improved. The star-catalogue of Ulugh Beig (originally written in Persian), with the exception of a part of the southern stars of Ptolemy not visible ([180]) in the latitude of 39° 52′ (?), was prepared in the Gymnasium at Samarcand from original observations. It contained at first only 1019 positions of stars, which are reduced to the year 1437. A later commentary furnishes 300 additional stars observed by Abu-Bekri Altizini in 1533. Thus we come, through Arabians, Persians, and Moguls, down to

the great epoch of Copernicus, and almost to that of Tycho Brahe.

Since the beginning of the 16th century the extension of navigation in tropical seas and high southern latitudes has operated powerfully in enlarging the knowledge of the firmament, though it has done so in a less degree than has the employment of telescopes, began a century later. By both, new regions of space before unknown have been opened to our view. I have noticed in a previous volume ([181]) what was related of the magnificence of the Southern Hemisphere, first by Amerigo Vespucci, and next by Magellan and by Elcano's companion Pigafetta, and how the black patches (Coal sacks) were described by Vicente Yañez, and the Magellanic Clouds by Anghiera and Andrea Corsali. Here, also, contemplative astronomy preceded measuring astronomy. The riches of the firmament near the South Pole,—a region which is really, as is now well known, comparatively poor in stars,—were described with such exaggeration, that Cardanus Polyhistor said that Vespucci saw there 10000 stars with his unassisted eyes. ([182]) The first persons who seriously began the task of observing the stars of the Southern Hemisphere were Friedrich Houtmann and Petrus Theodori of Emden (who, according to Olbers, was the same person as Dircksz Keyser). They measured distances of stars at Java and Sumatra, and the most southern stars were now entered in the celestial maps of Bartsch, Hondius, and Bayer, as well as, by the diligent care of Kepler, in the Rudolphine star-catalogue of Tycho Brahe.

Scarcely half a century after Magellan's circumnavigation of the globe, Tycho Brahe began his admirable examination of the position of the fixed stars,—a work surpassing in

exactness anything which practical astronomy had yet furnished, even the careful observations of the fixed stars by the Landgrave Wilhelm IV. at Cassel. Tycho Brahe's Catalogue, revised by Kepler, contains, however, only 1000 stars, of which $\frac{1}{4}$th at the utmost are of the 6th magnitude. This catalogue, and the less used one of Hevelius, having 1564 determinations of places of stars for the year 1660, are the last which (owing in the latter case to the obstinate aversion of the Dantzig astronomer to the application of telescopes to measuring instruments) were drawn up from observations made with the unassisted eye.

The combination of the telescope with measuring instruments made it at length possible to determine the places of stars below the 6th magnitude, and especially between the 7th and 12th magnitudes. Astronomers now first began to approach the time when they might be said to take possession of the world of fixed stars. But the enumeration of the feebler telescopic stars, and the determination of their places, have not only, by extending the horizon of the field of observation, given us to know more of the contents of the remoter regions of space,—but they have also, which is yet more important, exercised indirectly a material influence on our knowledge of the structure of the Universe and of its form, on the discovery of new planets, and on the more rapid determination of their paths. When William Herschel conceived the happy thought of, as it were, casting the sounding lead into the depths of space, and in his star gaugings (183) counting the stars which passed through the field of his great telescope at different distances from the Milky Way,—the law of the increasing quantity of stars in approaching the Milky Way was discovered, and brought with it the idea

of the existence of great concentric rings filled with millions of stars, forming the Galaxy. The knowledge of the number and relative position of the fainter stars, as has been shown by Galle's prompt and happy discovery of Neptune, and by that of several of the smaller planets, facilitates the discovery of planetary bodies which change their place, moving amidst fixed points. Another circumstance shows, in a still clearer light, the importance of very complete star-catalogues. When once a new planet has been discovered in the celestial vault, the difficult calculation of its path is aided by its rediscovery in a catalogue of older date. The fact of a star having been formerly registered, and being now missing in the position assigned to it, has thus often effected more than, from the slowness of the planet's motion, could be gained by the most carefully-repeated measurement during several successive years. Thus for Uranus, the star No. 964 in the Catalogue of Tobias Mayer, and for Neptune, the star 26266 in the Catalogue of Lalande, (184) have been of great importance. We now know that Uranus was observed 21 times before it was known to be a planet: once by Tobias Mayer, 7 times by Flamsteed, once by Bradley, and 12 times by Le Monnier. We may say, that the increasing hope of future discoveries of planetary bodies rests partly on the excellence of our present telescopes (Hebe, when discovered in July 1847, was equal to a star of between the 8th and 9th magnitudes, but in May 1849 was only of the 11th magnitude), and partly, and perhaps still more, on the completeness of our catalogues and the care of our observers.

Subsequent to the epoch when Morin and Gascoigne combined telescopes with measuring instruments, the first star-

catalogue which was published was that of Halley's southern stars. It was the fruit of a short visit to Saint Helena in 1677 and 1678, but it contained no determination of any star below the 6th magnitude. (185) It is true that Flamsteed had previously undertaken his great Star Atlas, but the work of that celebrated man was not published until 1712. It was followed by the observations of Bradley (1750 to 1762), which led to the discovery of aberration and nutation, and received a further lustre from our Bessel, in his Fundamenta Astronomiæ (1818); (186) and by the star catalogues of Lacaille, Tobias Mayer, Cagnoli, Piazzi, Zach, Pond, Taylor, Groombridge, Argelander, Airy, Brisbane, and Rümker.

We cite here only works which embrace large masses, (187) and present to us an important part of the contents of space in stars between the 7th and 10th magnitudes. The catalogue which is known under the name of Jérôme de Lalande, but which is founded on observations made by his nephew, Le Français de Lalande, and Burckhardt, between 1789 and 1800, has lately, though for the first time, received a great acknowledgment. In the state to which it has been brought by the careful reduction, editorship, and publication, for which astronomy is indebted to Francis Baily and the British Association for the Advancement of Science, it contains 47390 stars, many of which are of the 9th, and several rather below the 9th magnitude.* Harding, the dis-

[*The star-catalogues of Lalande and Lacaille, the first containing upwards of 47000 stars (as stated in the text), and the second above 10000 stars, were reduced, catalogued, and prepared for publication at the cost of the British Association for the Advancement of Science, the first under the superintendence of Mr. Francis Baily, and the second under that of Professor

coverer of Juno, has entered above 50000 stars in 27 sheets. Bessel's great work of the observations of Zones of the Heavens, comprising 75000 observations, and which extended, in the years 1825—1833, from $-15°$ to $+45°$ of declination, has been continued by Argelander of Bonn, from 1841 to 1844, with a care deserving of the highest praise, and has been carried by him to $+80°$ of declination. From Bessel's Zones, between $-15°$ and $+15°$ of declination, Weisse of Cracow, at the request of the Academy of St. Petersburg, has reduced 31895 stars (of which 19738 are of the 9th magnitude) to the year 1825. (188) Argelander's "Review of the Northern Heavens from $+45°$ to $+80°$ of declination," contains 22000 well-determined places of stars.

I think that I cannot refer to the great work of the star maps of the Berlin Academy more worthily than by introducing, in Encke's own words, an extract on the subject of this undertaking from his comprehensive discourse in memory of Bessel. "With the completion of catalogues is connected the hope that, by continued careful comparison of the stars marked as fixed points with the aspect of the heavens at the time of observation, we shall be enabled to

Henderson. But the expense of *printing* these two catalogues was defrayed by Her Majesty's Government, in consequence of a representation of their importance to the purposes of practical Astronomy made by the British Association to the late Sir Robert Peel.

The catalogues of Lelande and Lacaille are distinct from the "British Association Catalogue," not noticed in this part of the text of Cosmos, but frequently referred to in the course of the volume. The "British Association Catalogue" was also prepared under the superintendence of Mr. Francis Baily, but in its case the cost of printing, as well as that of preparing for publication, was defrayed by the contributions of the members of the British Association.—Ed.]

note all heavenly bodies which change their place, but whose movements, from the faintness of their light, it would be scarcely possible to perceive directly by the eye; and in this manner we may anticipate the discovery of all that still remains unknown to us in our solar system. As Harding's excellent Atlas offers a complete picture of the heavens, so far as Lalande's Histoire Celeste, on which it is founded, is capable of affording such a picture, so Bessel, in 1824, after finishing the first section of his Zones, formed the plan of founding thereupon a still more detailed representation of the sidereal heavens, which should have for its object, not merely the reproduction of observation, but the systematic attainment of a degree of completeness which should permit every new phenomenon to be immediately recognised. The star maps of the Berlin Academy of Sciences, sketched upon Bessel's plan, although they have not yet completed the first proposed cycle, have already attained their object in the discovery of new planets in the most brilliant manner, as up to the present time (1850) they have been the principal, though not the exclusive, means of the discovery of seven new planets. ([189]) Of the 24 sheets which are to represent the heavens within 15 degrees on either side of the Equator, our Academy has now published 16. They contain, as nearly as possible, all stars down to the 9th, and partially down to the 10th magnitudes."

I may here introduce a notice of the approximate estimations which have been hazarded respecting the number of stars in all parts of the heavens which may be visible to human eyes, aided by our present powerful space-penetrating telescopes. For Herschel's 20-feet reflector, which was

used in the celebrated star-gaugings or sweeps, with a magnifying power of 180, Struve takes for the zones within 30° on either side of the Equator, 5800000 stars; and, for the whole heavens, 20374000 stars. With a still more powerful instrument, the 40-feet reflector, Sir William Herschel supposed that 18 millions of stars would be visible in the Milky Way alone. ([190])

Having considered the number of fixed stars, whether telescopic or visible to the naked eye, which have been entered in catalogues, together with the determination of their places, we now turn to their distribution and grouping on the celestial vault. We have seen that, from their small and exceedingly slow (apparent and real) change of place, due partly to precession and the unequal influence of the progressive movement of our solar system, and partly to their own proper motion, they may be regarded in the light of fixed marks in space, enabling the attentive observer to recognise all bodies moving amongst them, either at a more rapid rate or in a different direction, as planets and telescopic comets. In gazing on the vault of heaven, our first and leading interest is attracted by the bodies which by their multitude and mass fill space,—it is the fixed stars which claim and receive the homage of our admiration: but the orbits of the moving planetary bodies speak more to the investigating reason, to which they present complicated problems, whose study promotes and accelerates intellectual development in the domain of astronomy.

From the multitude of stars, large and small, which appear intermingled, as it were by accident, on the celestial vault, the rudest tribes of men (as several now carefully-

examined languages of what are called savage nations testify) single out particular, and almost everywhere the same, groups, in which bright stars attract the eye, either by their proximity to each other, by peculiarities in their arrangement and relative position, or by a certain degree of isolation. Such groups awaken obscurely the idea of a relation of parts to each other; and, each being regarded as a whole, receive particular names, differing in different tribes, and most often taken from organic beings with which imagination peoples the silent regions of space. Thus there were early distinguished the Pleiades (called by some the brood of chickens), the seven stars of the Great Bear or Wain (the lesser Bear or Wain was remarked later, and only on account of the repetition of the form), Orion's Belt (Jacob's Staff), Cassiopeia, the constellations of the Swan, the Scorpion, the Southern Cross (on account of the striking change of direction before and after culmination), the Southern Crown, the Feet of the Centaur (as it were the Twins of the Southern Hemisphere), &c.

Where steppes, grassy prairies, or sandy deserts, present a wide horizon, the rising and setting of the constellations, varying with the seasons of the year, and associated thereby with the requirements of pastoral and agricultural life, become the subject of diligent attention, and are also gradually connected with symbolical combinations of ideas. Contemplative, not measuring, astronomy then begins to be more developed. Besides the diurnal movement common to all heavenly bodies from morning to evening, it is soon perceived that the sun has a movement of its own, much slower, and in the opposite direction. The stars which, when night comes on, are seen high in the evening sky, sink daily more

and more towards the setting sun, until at last they are lost in his beams, and disappear in the twilight; on the other hand, the stars which shone in the morning sky before sunrise recede more and more from the Sun. In the constantly changing spectacle of the starry heavens, fresh and fresh constellations show themselves. With some degree of attention it is easily recognised that they were the same which had before become invisible in the West; and that, in the course of about half a year, those stars, which before were seen near the Sun, are now opposite to it, setting when it rises, and rising when it sets. From Hesiod to Eudoxus, and from Eudoxus to Aratus and Hipparchus, the literature of the Greeks is full of allusions to the disappearance of stars in the Sun's rays (their heliacal setting), and their becoming visible in the morning twilight (their heliacal rising). The accurate observation of these phenomena presented the first elements of chronology—elements which were simply expressed in numbers; while at the same time, mythology, varying in its imaginations with the gay or gloomy dispositions of the national mind, exercised without restraint its capricious sway in the fictions connected with the bright bodies of space.

The primitive Greek sphere (I here follow again, as in the history of the Physical Contemplation of the Universe, [191] the researches of my too early departed friend, the illustrious Letronne) became gradually filled with constellations, without their having been in the commencement referred in any way to the Ecliptic. Thus Homer and Hesiod distinguish different groups of stars, as well as single stars, by particular names: Homer notices the She Bear ("else called the Wain of Heaven, and which alone never descends to

bathe in the ocean"), Bootes, and the Dog of Orion; and Hesiod names Sirius and Arcturus; both speak of the Pleiades, the Hyades, and Orion. ([192]). If Homer twice says that the Bear *alone* never plunges into the ocean, this merely implies that in his time the constellations of the Dragon, Cepheus, and the Little Bear, which also never set, had not yet been placed in the Greek Celestial Sphere. It by no means implies that the existence of the stars forming these three catasterisms was not known, but only that they had not yet been arranged in figures. A long and often misunderstood passage of Strabo (lib. i. p. 3, Casaub.) on Homer (Il. xviii. 485—489) proves rather than anything else that which is here important—viz., the *gradual* acceptance of figures or constellations in the Grecian Sphere. "It is unjustly," says Strabo, "that Homer is accused of ignorance, as if he knew only of one Bear instead of two. Perhaps the second was not yet constellated, and that it was only after the Phœnicians had marked out this constellation, and used it in navigation, that it came to the Greeks." All the scholiasts on Homer, Hygin, and Diogenes Laertius, ascribe the introduction to Thales. The Pseudo-Eratosthenes calls the Little Bear φοινικη (as it were the Phœnician Lode-star). One hundred years later (Ol. 71), Cleostratus of Tenedos enriched the Sphere with Sagittarius, τοξότης, and the Ram, κριός.

It is to this epoch, that of the tyranny of the Pisistratides, that we are to ascribe, according to Letronne, the introduction of the Zodiac in the ancient Greek Sphere. Eudemus of Rhodes, one of the most distinguished disciples of Aristotle, author of a "History of Astronomy," ascribes the introduction of the Zodiacal Zone (ἡ τοῦ ζωδιακοῦ διάζωσις,

also ζωίδιος κύκλος) to Œnopides of Chios, a cotemporary of Anaxagoras. (193) The idea of referring the planets and fixed stars to the Sun's path, and the division of the Ecliptic into twelve equal parts (Dodecatomeria), are ancient Chaldean, and it is highly probable that they reached the Greeks from Chaldea itself, and not from the Valley of the Nile, and, at earliest, at the beginning of the 5th or in the 6th century before our Era. (194) The Greeks only selected from the constellations already marked in their primitive Sphere those which were nearest to the Ecliptic, and which could be employed as Signs of the Zodiac. If anything more than the idea and the number of divisions of a zodiac,—if the zodiac itself, with its signs,—had been borrowed by the Greeks from another nation, 11 signs would not have been thought sufficient originally; nor would the Scorpion have been applied to two divisions; nor would zodiacal figures have been formed,—some of which, as Taurus, Leo, Pisces, and Virgo, cover, with their outlines, 35° to 48°; while others, as Cancer, Aries, and Capricornus, occupy only 19° to 23°,—which deviate inconveniently to the North and South of the Ecliptic,—which sometimes are widely separated, and sometimes, like Taurus and Aries, Aquarius and Capricornus, are closely crowded and almost overlap. All these circumstances prove that earlier-formed catasterisms were made into zodiacal signs.

According to Letronne's conjecture, the sign Libra was introduced in the time of Hipparchus,—perhaps by himself. Eudoxus, Archimedes, Autolycus, and even Hipparchus, in the few remains of theirs which we possess (with the exception of one passage, probably falsified by a copyist), (195) never mention it. We first find a notice of the new sign

in Geminus and Varro, hardly half a century before our Era; and as the Romans soon after this date, from Augustus to Antoninus, became vehemently attached to astrology, those constellations "which lay along the Sun's celestial path" grew into a heightened fanciful importance. To the first half of this period of the Roman Empire belong the Egyptian zodiacal figures of Dendera, Esne, the Propylon of Panopolis, and some mummy cases,—as was asserted by Visconti and Testa at a time when all the materials for the decision of the question had not yet been collected, and when wild hypotheses prevailed respecting the signification of those symbolical zodiacal signs, and their dependence on the precession of the equinoxes. From Adolph Holtzmann's acute researches, the high antiquity which, from passages in Menu's Institutes, Valmiki's Ramayana, and Amarasinha's Dictionary, August Wilhelm von Schlegel had attributed to zodiacs found in India, has become very doubtful. ([196])

The artificial grouping of stars in constellations which, in the course of centuries, has taken place in so accidental a manner,—the often inconvenient magnitude and uncertain outlines of these figures,—the confused nomenclature of separate stars in the constellations, with the exhaustion of several alphabets, as in the Ship Argo,—the incongruous mixture of mythical personages with the plain prose of physical instruments, chemical furnaces, and pendulum clocks, in the southern hemisphere,—have several times led to proposals for a new division of the celestial sphere, which should be entirely without imaginary figures. For the southern hemisphere, where only Scorpio, Sagittarius, Centaurus, Argo, and Eridanus, have ancient poetic possession, the enterprise would seem less hazardous. ([197])

The heaven of the fixed stars (orbis inerrans of Apuleius), and the improper expression "fixed stars" (astra fixa of Manilius), remind us, as I have already remarked in the Introduction to the portion of this volume which treats of Astrognosy, (198) of the combination and even confusion which has taken place between the two ideas of "being set or fastened in the sky," and of "absolute immobility or fixity." When Aristotle terms the non-wandering orbs (ἀπλανῆ ἄστρα) fastened (ἐνδεδεμένα), and when Ptolemy calls them attached (προσπεφυκότες), these expressions have a direct reference to Anaximenes' supposition of a crystal sphere. The apparent motion of all the fixed stars from East to West, while their distances from each other remained the same, had given rise to this hypothesis. "The fixed stars (ἀπλανῆ ἄστρα) belong to the upper or more remote region, in which they are fastened as if nailed to the crystal heaven; the planets (ἄστρα πλανωμενα or πλανητά), which have an opposite motion, belong to the lower or nearer region." (199) If, in Manilius, as early as the times of the first Cæsars, "stella fixa" is used instead of "infixa" or "affixa," we may still assume that the school of Rome kept only at first to the original meaning of being fastened; but that, as the word "fixus" also included the signification of "immobility," and might even be taken as synonymous with "immotus" and "immobilis," it might easily happen that popular opinion, or rather the usage of language, should gradually connect with "stella fixa" the idea of immobility, without remembering the sphere in which the stars had been supposed to be fastened: and thus Seneca might term the world of fixed stars "fixum et immobilem populum."

If, following Stobæus and the collector of the "Views of

Philosophers," we carry back the expression of "crystal heaven" to the early time of Anaximenes, we find, however, the idea which forms the groundwork of such an appellation first developed with precision by Empedocles. He regards the heaven of the fixed stars as a solid mass, formed from the æther which has been solidified into a crystalline substance by heat. (200) The Moon is regarded by him as a body which has been molten as by the action of fire, and subsequently consolidated like hail. The original idea of transparent solidified substances would not, according to the physics of the Ancients, (201) and their ideas of the solidification of fluids, have led directly to cold and ice; but the affinity of κρύσταλλος with κρύος and κρυσταινω, as well as comparison with the most transparent of all bodies, gave occasion to the more definite statements, that the vault of heaven consisted of ice or of glass. Thus we find in Lactantius "cœlum aërem glaciatum esse," and "vitreum cœlum." Empedocles was certainly not thinking of Phœnician glass, but of air which, by the action of the fiery æther, had been run together into a transparent solid body. In the comparison with ice (κρύσταλλος), the prevailing idea was that of transparency: the origin of ice by the action of cold was not regarded, all that was directly considered being the case of a fluid which had become solid and was transparent. If the poets used the word *crystal*, in prose (as is testified by the passage of Achilles Tatius, the commentator of Aratus, cited in Note 200,) the expression employed is only *crystalline*, or *similar to crystal* (κρυσταλλοειδης). So also πάγος (from πήγνυσθαι, to solidify) signifies a piece of ice, in which the solidification is the only thing considered.

Through the Fathers of the Church, who, in allusions

to the subject, assume from seven to ten glass heavens successively placed over each other like the coats of an onion, this view of the crystal vault passed to the Middle Ages: it has even been preserved to recent times in some of the convents of the south of Europe, where, to my astonishment, a venerable dignitary of the Church, in reference to the fall of aerolites at Aigle which excited so much attention, expressed the opinion that what we called meteoric stones, and which were covered with a vitrified crust, were not parts of the fallen stone itself, but pieces of the crystal heaven which it had broken through in falling. Kepler first, two centuries and a half earlier, induced by the consideration of comets cutting through all the planetary orbits, had boasted ([202]) of having destroyed the 77 homocentric spheres of the celebrated Girolamo Fracastoro, as well as all the more ancient retrograding epicycles. How such great minds as Eudoxus, Menæchmus, Aristotle, and Apollonius of Perga, had conceived to themselves the possible mechanism and motion of spheres intercalated with each other, and carrying with them the planets,—or whether they regarded these spherical systems as ideal contemplations—fictions of the intellect—by the aid of which the difficult problems of the courses of the planets might be explained and approximately computed,—are questions which I have touched on elsewhere, ([203]) and which are not without importance in the history of astronomy, when that history attempts to distinguish periods of development.

Before we pass from the very ancient but artificial zodiacal grouping of the fixed stars (as imagined to be set in a solid sphere) to their natural or real grouping, and to such

laws in respect to their relative distribution as have hitherto been recognised, we have still to consider some particular appearances presented by them to our sense of vision; viz. their rays, their apparent unreal diameters, and the diversities of colour of different stars. Of the apparent rays, which differ in number, position, and length, as seen by every individual, I have already spoken when treating of the subject of Jupiter's satellites. [204] Indistinct vision (la vue indistincte) arises from various organic causes, dependent on the spherical aberration of the eye, on diffraction at the margins of the pupils or at the eye-lashes, and on the irritability of the retina spreading more or less widely from a stimulated point. [205] I see very regularly, in stars from the 1st to the 3d magnitude, eight rays, at angles of 45°. As, according to Hassenfratz, these rays are caustics on the crystalline, formed by the intersection of the refracted rays, they move according as the spectator inclines his head to either side. [206] Some of my astronomical friends see three or at most four upward, and no downward rays. It has always appeared to me remarkable that the ancient Egyptians invariably give to stars five rays only (at every 72°); so much so, that, according to Horapollo, a star signifies in hieroglyphics the number 5. [207]

These rays disappear if the star is viewed through a small hole made in paper with a needle (I have often observed Canopus, as well as Sirius, in this manner). The rays appear in telescopic vision with high magnifying powers, when the stars present themselves either as luminous points of more intense light, or as extremely small discs. Although the less degree of scintillation between the tropics gives a certain impression of repose, yet the entire absence of rays, in viewing

the heavens with the naked eye, would appear to me a privation. Illusion of the senses, and indistinctness of vision, may perhaps augment the magnificence of the shining canopy of heaven. Arago long ago proposed the question—Why is it that, notwithstanding the strong light of the fixed stars, we do not perceive them when rising above the horizon, whilst yet we see the extreme margin of the moon's disc under similar circumstances? ([208])

Even the most perfect optical instruments, with the highest magnifying powers, give to the fixed stars false diameters (spurious discs, diamètres factices), which, according to Sir John Herschel's remark, ([209]) "with equal magnifying powers diminish as the aperture of the telescope increases." Occultations of stars by the Moon's disc show that immersion and emersion are sensibly instantaneous,—so much so, that no fraction of a second can be assigned for the time occupied in disappearance or reappearance. The frequent observation of stars in their immersion adhering to the disc of the moon, is a phenomenon of the inflection of light which has no connection with the question of the star's diameter. I have already noticed elsewhere, that Sir William Herschel, with a magnifying power of 6500, still found the diameter of $\alpha$ Lyræ 0″·36. The image of Arcturus was so lessened in a thick mist as to be even below 0″·2. It is remarkable that, from the illusion produced by irradiation, Kepler and Tycho Brahe, before the invention of telescopes, ascribed to Sirius a diameter, the one of 4′, the other of 2′ 20″. ([210]) The alternating light and dark rings which surround the factitious discs of stars, viewed with magnifying powers of two or three hundred, and which, when diaphragms of different shapes are applied, show prismatic colours, are the consequences at once

of interference and of diffraction, as we learn from Arago's and Airy's observations. The smallest objects which can still be distinctly seen (telescopically) as luminous points (multiple stars such as ε Lyræ, and the 5th and 6th star discovered by Struve in 1826 and by Sir John Herschel in the trapezium, (211) formed by the quadruple star θ Orionis) may be employed to test the quantity of light and merits in other respects of optical instruments, whether refractors or reflectors.

A difference of colour in the proper light of the fixed stars, as well as in the reflected light of the planets, has been recognised from very early times; but the knowledge of this remarkable phenomenon has been wonderfully enlarged since the period of telescopic vision, and especially since double stars have become an object of lively interest and diligent observation. We do not here refer to the change of colour which, as has been already remarked, acccompanies scintillation even in the whitest heavenly bodies,—still less the transitory and most frequently reddish tinge which the light of stars receives in the vicinity of the horizon from the medium (*i. e.* the atmospheric strata) through which we view them; but we speak of the white or of the coloured light which radiates from stars as the result of peculiar luminous processes and the particular character of the surface of each. The Grecian astronomers knew only red stars; while, by the aid of the telescope, the moderns have discovered in the starry vault,—in the celestial fields which light traverses, as in the corollas of our flowering plants, and in the metallic oxides,—almost every gradation of prismatic colour between the two extremes of refrangibility, or

between the violet and the red rays. Ptolemy, in his catalogue of the fixed stars, calls six stars ὑπόκιρροι, fiery red, (212) viz.—Arcturus, Aldebaran, Pollux, Antares, Betelgueze, and Sirius. Cleomedes even compares Antares with the red hue (213) of Mars, which is itself called sometimes πυρρὸς, and sometimes πυροειδὴς.

Of the six stars above enumerated, five have still, in our days, a red or reddish light: Pollux is still marked in our catalogues as reddish, whereas Castor is said to be greenish. (214) Sirius, on the other hand, offers the solitary example of an historically-proved alteration of colour, for it has at present a perfectly white light. Some great revolution of nature (215) must doubtless have taken place on the surface or in the photosphere of such a fixed star,—such a distant *sun*, as already Aristarchus of Samos would have called the fixed stars,—to disturb the process by which, through the absorption of other complementary rays (whether in the photosphere of the star itself, or in wandering cosmical clouds), the less refrangible red rays had once been the prevailing ones. Now that, from the modern advances in optics, this subject has become one of great and lively interest, it would be very desirable to be able to assign some fixed limits in point of time to the epoch of such an event in Nature as that of the disappearance of the red colour of Sirius. In the time of Tycho Brahe the light of Sirius must certainly have been already white; for when the new star which appeared in Cassiopeia in 1572, and which was at first of dazzling whiteness, was seen to assume, in March 573, a red tinge, and, in January 1574, to become once more white,—the astonished observers who witnessed these changes compared the red star to Mars and Aldebaran, but not to Sirius. Perhaps Sédillot, or other philologists

conversant with Arabian and Persian astronomy, may succeed in discovering in the intervals from El-Batani (Albategnius) and El-Fergani (Alfraganus) to Abdurrahman Sufi, and Ebn-Junis (from 880 to 1007), and from Ebn-Junis to Nassir-Eddin and Ulugh Beig (from 1007 to 1437), some evidence respecting the colour of Sirius at that time. El-Fergani (properly called Mohammed Ebn-Kethir El-Fergani), who, as early as the middle of the 10th century, observed at Rakka (Aracte) on the Euphrates, names as "red stars" ("stellæ ruffæ" in the old Latin version of 1590) Aldebaran, and, perplexingly enough, (216) the now yellow, or at the utmost reddish-yellow, Capella, but not Sirius. On the other hand, if we suppose that Sirius had then ceased to be a red star, it would seem strange that El-Fergani, who follows Ptolemy throughout, should not have pointed out the change of colour in a star of such note. Negative reasons are, however, seldom conclusive; and it should be remarked that, in the same passage, El-Fergani does not mention the colour of Betelgeuze ($\alpha$ Orionis), which is now, as in Ptolemy's time, a red star.

It has long been recognised, that among all the brightly-shining fixed stars in the heavens, Sirius occupies the first and most important place in chronological respects, and in its historical connection with the earliest development of human civilization in the Valley of the Nile. According to the most recent researches of Lepsius, (217) the Sothic period, and the heliacal rising of Sothis (Sirius),—on which subject Biot has furnished an excellent memoir,—remove the complete construction of the Egyptian calendar to the highly ancient epoch of almost 33 centuries before our Era, when not only the summer solstice, and consequently the commencement

of the rising of the Nile, but also the heliacal rising of Sothis, fell upon the day of the first water-month (on the first Pachon). The most recent and hitherto unpublished researches on the etymology of Sothis and Sirius in the Coptic, the Zend, the Sanscrit, and the Greek, have been brought together by me in a note (218), which cannot be otherwise than welcome to those who, from interest in the history of astronomy, are led to recognise, in languages and their affinities, monuments of earlier knowledge.

At the present time, besides Sirius; Vega, Deneb, Regulus, and Spica, are decidedly white stars; and among the small double stars, Struve counts 300 in which both stars are white. (219) Procyon, Atair, Polaris, and especially $\beta$ Ursæ Minoris, have a yellow or yellowish light. Of red or reddish large stars, we have already named Betelgeuze, Arcturus, Aldebaran, Antares and Pollux. Rümker finds $\gamma$ Crucis to have a fine red colour; and my old friend Captain Bérard, who is an excellent observer, wrote from Madagascar in 1847, that he had for some years perceived $\alpha$ Crucis to be reddening. The star $\eta$ Argûs, which has acquired celebrity from Sir John Herschel's observations, and of which I shall soon have occasion to speak in more detail, is changing the colour as well as the intensity of its light. In 1843, at Calcutta, Mr. Mackay found this star like Arcturus in colour, —therefore of a reddish yellow; (220) but in February 1850, Lieutenant Gilliss, in letters from Santiago de Chile, calls it "of a darker colour than Mars." Sir John Herschel, at the conclusion of his Cape observations, gives a list of 76 ruby-coloured small stars, from the 7th to the 9th magnitude. The appearance of some of them in the telescope is like drops of blood. The majority of "variable" stars are described

as red or reddish. (221) I may name as exceptions—Algol in the head of Medusa, $\beta$ Lyræ, and $\varepsilon$ Aurigæ, which have a pure white light. Mira Ceti, whose periodic variation of light was the first recognised, (222) has a strongly reddish light; but the variability of Algol and $\beta$ Lyræ shows that the red colour is not a necessary condition of variability of light; and we know, moreover, that there are several reddish stars which are not included among the variable stars. According to Struve, the faintest stars in which colours can still be distinguished are of the 9th and 10th magnitudes. We find the first mention of blue stars (223) in Mariotte's "Traité des Couleurs," in 1686. The star $\eta$ Lyræ is bluish. A small cluster of $3\frac{1}{2}$ minutes' diameter in the southern hemisphere consists, according to Dunlop, exclusively of small blue stars. Among the double stars there are many in which the principal star is white, and the companion blue; and some in which both the principal star and the companion have a blue light, (224) as $\delta$ Serp. and 59 Androm. Sometimes, as in the cluster of stars near $\kappa$ of the Southern Cross, which was taken by Lacaille for a nebula, above a hundred small stars of different colours (red, green, blue, and bluish-green) are so crowded together, that they appear, in large telescopes, like gems of many colours ("like a superb piece of fancy jewellery)." (225)

The ancients thought they recognised a remarkable symmetrical arrangement in the position of certain stars of the 1st magnitude. Thus their attention was particularly directed to what they called the "four royal stars," which are opposite to each other on the sphere—Aldebaran and Antares, Regulus and Fomalhaut. This regular arrange-

ment, which I have noticed elsewhere,(226) is discussed at length by a Roman writer of the age of Constantine, Julius Firmicus Maternus.(227) The differences in right ascension of the "royal stars," "stellæ regales," are 11h. 57m. and 12h. 49m. The importance which was attached to this subject was probably founded on opinions derived from the East, which, under the Cæsars, made their way into the Roman empire, together with a great predilection for astrology. An obscure passage in the book of Job (ch. ix. v. 9), in which the "chambers of the south" are opposed to "the Leg," *i. e.* the North Star in the Great Bear (the celebrated Bull's Leg in the astronomical representations at Dendera, and in the Egyptian "Book of the Dead"), seems also intended to allude to the four quarters of the heavens, marked by four constellations.(228)

If a large and fine portion of the southern heavens,—viz. all stars beyond 53° of south declination,—remained concealed from the ancients, and even until the latter part of the Middle Ages, yet the knowledge of the southern celestial hemisphere had gradually become complete about one hundred years before the invention and employment of telescopes. In the time of Ptolemy, the Altar, the feet of the Centaur, the Southern Cross then included in the Centaur, or otherwise (according to Pliny) called Cæsaris Thronus in honour of Augustus, (229) and lastly Canopus (Canobus), which the scholiast to Germanicus (230) calls the Ptolemæon,—were all visible above the horizon of Alexandria. In the catalogue of the Almagest, Achernar, a star of the 1st magnitude, the last in the constellation of the River Eridanus (in Arabic, Achir-el-nahr), is also mentioned, although it was 9° below the horizon. Intelligence of the existence of this star must

have been brought to Ptolemy from voyages to the southern part of the Red Sea, or between Ocelis and the commercial entrepôt of Muziris ([231]) on the Malabar coast. No doubt Diego Cam in company with Martin Behaim, in 1484, on the West Coast of Africa, Bartholomew Diaz in 1487, and Vasco de Gama in 1497 on the voyage to India, passed far beyond the Equator, and into the Southern Ocean as far as 35° S. latitude; but the first particular notice of the large stars and nebulæ, the description of the Magellanic clouds and the "coal sacks," and even the fame of the "wonders of the heavens not seen in the Mediterranean," belong to the epoch of Vincent Yañez Pinzon, Amerigo Vespucci, and Andrea Corsali, between 1500 and 1515. Star-distances were measured in the southern heavens at the end of the 16th and the beginning of the 17th century. ([232])

Laws of relative density in the distribution of the fixed stars on the celestial vault began to be recognised when William Herschel, in 1785, conceived the happy thought of estimating the number of stars visible in the field of view, 15′ in diameter, of his 20-feet reflector, at different altitudes and in different directions. This laborious process of "gauging the heavens" has been already repeatedly referred to in the present work. The field of view embraced each time only $\frac{1}{833000}$th of the whole heavens; and, according to a remark of Struve's, 83 years would be required for the completion of such gaugings over the entire sphere. ([233]) In inquiries respecting the equal or unequal distribution of stars, their photometric magnitudes must be particularly taken into account. If we confine our attention to the bright stars of the first three or four classes of magnitude, we find them pretty uniformly distributed ([234]) on the whole;

but locally, in the southern hemisphere, from ε Orionis to α Crucis, rather crowded together in a superb zone in the direction of a great circle. The disagreement in the judgments pronounced by different travellers, as to the relative beauty of the northern and southern hemispheres, has often I believe, depended only on the circumstance, that some of the observers had visited the southern regions at a time when the finest constellations culminate in the day-time. From the gaugings of the two Herschels in the northern and southern celestial hemispheres, it follows that the fixed stars, from the 5th and 6th magnitudes down to the 10th and 15th magnitudes, (particularly, therefore, telescopic stars), increase regularly in density as the Milky Way (ὁ γαλαζιας κύκλος) is approached; and thus that there may be said to be poles of abundance or richness, and poles of scarcity or poverty, in respect to stars,—the latter being at right angles to the principal axis of the Milky Way. The density of stars is least at the poles of the galactic circle, and increases in all directions,—at first slowly, and then more and more rapidly as the galactic polar distance increases.

By an ingenious and careful consideration of the results of the star-gaugings which we possess, Struve finds that, on the average, there are, in the central parts of the Milky Way, 29·4 times (almost 30 times) as many stars as in the regions around the poles of the Milky Way; and in northern galactic polar distances of 0°, 30°, 60°, 75°, and 90°, the ratios of the numbers of stars in the field of view of 15′ diameter are 4·15, 6·52, 17·68, 30·30, and 122·00. In the comparison of opposite zones, notwithstanding the great similarity in the law of increase in the number of stars, we again find an absolute preponderance (235) on the side of the richer and more beautiful southern heavens.

When, in the year 1843, I asked Captain Schwink to be so kind as to communicate to me the distribution, in right ascension, of the 12148 stars (1st to 7th magnitude inclusive), which, at Bessel's instance, he had entered in his "Mappa cœlestis," he found, in four groups—

| | | | | |
|---|---|---|---|---|
| Right | ascension, | 50°—140°; | 3147 | stars |
| " | " | 140°—230°; | 2627 | " |
| " | " | 230°—320°; | 3523 | " |
| " | " | 320°— 50°; | 2851 | " |

These groups agree with the still more exact results of the "Etudes stellaires;" according to which, the maxima of stars from the 1st to the 9th magnitude fall in the right ascensions of 6h. 40m. and 18h. 40m., and the minima in those of 1h. 30m. and 13h. 30m. (236)

In reference to conjectures respecting the structure of the Universe, and the position or depth of the sidereal strata, it is essential to distinguish, among the countless multitude of stars, those which are scattered sporadically, from those which we find crowded in detached independent groups. The latter are the "clusters of stars" which have been spoken of: they often contain many thousands of telescopic stars in recognisable relation to each other, and are seen by the naked eye as round or oval nebulæ, appearing like comets. These are the "nebulous stars" of Eratosthenes (237) and Ptolemy; the "nebulosæ" of the Alphonsine Tables of 1252, and those of Galileo, which (as it is said in the Nuncius sidereus) sicut areolæ sparsim per æthera subfulgent.

The clusters of stars, again, are either placed solitarily in the heavens, or else are closely and unequally crowded, as it were in strata, in the Milky Way and in the two Magellanic clouds. The most numerous, and, in respect to the annular configuration of the Milky Way, the most important assemblage of "globular clusters," is in a region of the southern heavens, (238) between the Corona australis, Sagittarius, the tail of the Scorpion, and the constellation of the Altar (R. A. 16h. 45m.—19h.) But all the clusters of stars which are in or near the Milky Way are not round or globular: there are several of irregular outline, less rich in stars, and with not very dense centres. In many round groups the individual stars are of equal, and in others of unequal, magnitudes. In some rare cases they show a fine reddish central star (239); (R. A. 2h. 10m., N. Decl. 56° 21′). How such world-islands, with their multiplicity of suns, can rotate free and undisturbed, is a difficult problem in dynamics. Clusters of stars and nebulæ, even though it be now very generally assumed respecting the latter that they also consist of very small but still more distant stars, yet appear to be subject to different laws in respect to their local distribution. The recognition of these laws will have a prominent influence in modifying conjectures respecting what has been adventurously termed the "structure of the heavens." It is also a very remarkable fact of observation, that, with the same aperture and magnifying power of the telescope, round nebulæ are more easily resolved into clusters of stars than oval ones. (240)

Of the clusters of stars which form, as it were, detached systems, I content myself with naming the following:—

The Pleiades: doubtless recognised from the earliest

times by the rudest nations; the constellation of navigation, Pleias, *ἀπὸ τοῦ πλέιν*, according to the etymology of the old scholiast of Aratus, which is probably more correct than that of later writers, who derive the name from *πλέος*, abundance. The navigation of the Mediterranean lasted from May to the beginning of November,—from the early rising to the early setting of the Pleiades.

The Bee-hive in Cancer: according to Pliny, nubecula quam Præsepia vocant inter Asellos; a *νεφέλιον* of the Pseudo-Eratosthenes.

The cluster of stars in the hilt of the sword in Perseus, often mentioned by the Greek astronomers.

Coma Berenices: like the three former, visible to the naked eye.

Cluster of stars near Arcturus (No. 1663), telescopic; R. A. 13h. 34m. 12s., N. declination, 29° 14′; more than a thousand small stars of the 10th to the 12th magnitude.

Cluster of stars between $\eta$ and $\zeta$ Herculis: in *very* fine nights visible to the naked eye; a magnificent object in the telescope (No. 1968), with singular ray-shaped outlines; R. A. 16h. 35m. 37s.; N. Decl. 36° 47′; first described by Halley in 1714.

Cluster of stars near $\omega$ Centauri: described as early as 1677 by Halley; appears to the naked eye as a round comet-like patch, shining almost like a star of the 4.5 magnitude; when seen in powerful telescopes it appears to be composed of a countless multitude of small stars of the 13th to the 15th magnitude, which are more densely crowded towards the centre; R. A. 13h. 16m. 38s., S. Declination 46° 35′; No. 3504 in Sir John Herschel's

catalogue of the clusters of stars in the Southern Heavens, 15′ in diameter. (Cape Observ. pp. 21 and 105, Outl. of Astr. p. 595).

Cluster of stars near κ of the Southern Cross (No. 3435): composed of many-coloured stars of the 12th to the 16th magnitude, distributed over an area of $\frac{1}{48}$th of a square degree; a nebulous star according to Lacaille, but so completely resolved by Sir John Herschel that no nebulous appearance remained: the central star deep red. (Cape Observ. pp. 17 and 102, Pl. 1, fig. 2).

Cluster of stars 47 Toucani, Bode; No. 2322 of Sir John Herschel's catalogue, one of the most remarkable objects of the Southern heavens. I was myself deceived by it for some nights, taking it for a comet, when, on my first arrival in Peru, in 12° South latitude, I saw it rise high above the horizon. Its visibility to the naked eye is so much the greater because, although near the smaller Magellanic Cloud, it is in a place wholly devoid of stars, and has a diameter of 15′ to 20′. It is of a pale roseate colour in the inside, surrounded concentrically by a white border, and composed of small stars all about the same magnitude (14m. to 16m.), presenting all the characteristics of bodies of a globular form. [241]

Cluster of stars in the girdle of Andromeda, near the star ν of that constellation. The resolution of this celebrated nebula into stars, above 1500 of which have been distinctly made out, is one of the most remarkable discoveries of this department of astronomy in our time. Its merit belongs to George Bond, [142] assistant at the Observatory of Cambridge in the United States (March 1848); and it also evidences the excellence and abun-

dance of light of the refracting telescope of that Observatory (which has an object glass of 14 Parisian inches diameter), since even a reflecting telescope, in which the mirror has 18 inches diameter, does not shew the faintest trace by which the presence of a star can be divined. (243) The cluster of stars in Andromeda may perhaps have been known as a nebula of oval form as early as the end of the tenth century; but it is more certain that on the 15th of December, 1612, Simon Marius (Mayer of Guntzenhausen, the same who first remarked the change of colour in scintillation (244)), distinguished it as a new and wonderful starless cosmical body which had not been named by Tycho Brahe, and it was he who first gave a detailed description of it. Half a century later, Bouillaud, the author of the Astronomia philolaica, occupied himself with the same subject. This cluster of stars, which is $2\frac{1}{2}°$ long and above 1° broad, is particularly characterised by two remarkable very narrow black streaks, nearly parallel to each other and to the longer axis of the cluster, and, according to Bond's examination, traversing the whole like fissures. This arrangement reminds us strongly of the remarkable longitudinal fissure in an unresolved nebula of the Southern hemisphere, No. 3501, which has been described and figured by Sir John Herschel. (Cape Observ. pp. 20 and 105, Pl. IV. fig. 2.)

In this selection of remarkable clusters of stars, I have not included the great nebula in Orion's belt, notwithstanding the important discoveries for which we are indebted to the Earl of Rosse and his colossal telescope, as I prefer reserving it for the section on Nebulæ, although portions have thus been already resolved.

We find the greatest accumulation of clusters of stars (but by no means of nebulæ) in the Milky Way [245] (the Galaxy, the Celestial River [246] of the Arabians), which forms almost a great circle of the sphere, and is inclined to the equator at an angle of 63°. The poles of the Milky Way are situated in R. A. 14h. 47m., North Decl. 27°; and R. A. 0h. 47m., South Decl. 27°: therefore that which may be called the North pole is near Coma Berenices, and the South pole between Phœnix and Cetus. If all planetary relations of place are referred to the Ecliptic, *i. e.* to the great circle in which the plane of the sun's path cuts the sphere, we may with equal convenience refer many relations in space of the fixed stars, (for example their accumulation or grouping) to the approximate great circle of the Milky Way. In this sense, the latter is to the sidereal universe what the ecliptic is to the planetary world of our solar system. The Milky Way cuts the equator in the constellation of the Unicorn between Procyon and Sirius, R. A. 6h. 54m. (for 1800), and in the left hand of Antinous, R. A. 19h. 15m. Thus the Milky Way divides the celestial sphere into two rather unequal portions, whose areas are to each other in the proportion of about 8 to 9. The vernal point is situated in the smaller portion. The breadth of the Milky Way varies very much in different parts of its course. [247] Where it is narrowest, and at the same time brightest (between the prow of the Ship and the Cross, and nearest to the Southern Pole), its width is barely from 3° to 4°: at other points it is 16°, and in the divided part, between Ophiuchus and Antinous, [248] it is as much as 22°. William Herschel has remarked, that, judging by his star-gauging, the Milky Way is in many regions 6 or 7

degrees broader than the brightness visible to the naked eye. (249)

Huygens, who examined the Milky Way with his 23 feet refractor, had denied, as early as 1656, that its milky whiteness was to be attributed to unresolvable nebulæ. A more careful application of reflecting telescopes of the largest dimensions and greatest power of light, have subsequently proved with still more certainty, what Democritus and Manilius had already conjectured respecting the ancient path of Phaeton, viz. that the milky brightness was to be ascribed solely to the crowded strata of small stars, and not to the scantily interspersed nebulæ. The general white or shining appearance is the same in points where all can be perfectly resolved into stars, and even where these stars, thus viewed through the telescope, are seen to be projected on a black ground, entirely without any nebulous light. (250) It is in general a remarkable characteristic of the Milky Way, that globular clusters of stars, and nebulous patches of a regular oval shape, are equally rare in it, (251) whereas at a great distance from it both are congregated in large numbers; and in the Magellanic clouds we even find isolated stars, globular clusters in all states of condensation, and nebulæ both of definite oval and of wholly irregular form, intermingled. A remarkable exception to this rarity of globular clusters in the Milky Way occurs in a region of it which is situated between R. A. 16h. 45m. and 18h. 44m.; between the Altar, the Southern Crown, the head and body of Sagittarius, and the tail of the Scorpion. Between the stars ε and θ of the Scorpion, there is even one of those annular nebulæ which are so exceedingly rare in the southern celestial hemisphere. (252) In the field of view of

powerful telescopes (and we must remember that, according to the estimations of Sir William Herschel, a 20-feet instrument penetrates space to 900, and a 40-feet instrument to 2800 distances of Sirius), the Milky Way appears in different parts as varied in its sidereal contents, as it seems irregular and indeterminate in its outlines and boundary when viewed by the naked eye. If in some parts of the Milky Way large spaces exhibit great uniformity, both in respect to light and to the apparent magnitude of the stars of which it consists, in other parts the brightest patches of closely-crowded luminous points are interrupted in a granular, and even in a reticular manner, by darker intervals ([253]) which are poor in stars: indeed, in some of these intervals, quite in the interior of the galaxy, not even the smallest star (18th or 20th magnitude) can be discovered. One can hardly refrain from thinking, that in such places we really see through the whole sidereal stratum of the Milky Way. When gauging with a field of view of the telescope of 15′ diameter, the change is almost immediate from fields containing 40 or 50 stars on an average, to others having between 400 and 500 stars. Often, stars of the higher orders of magnitude occur in the midst of the finest "star dust," while all the intermediate magnitudes are wanting. Perhaps those stars which we call of the lower orders of magnitude do not always appear to us such solely on account of their enormous distance: it is also possible that they may really have less volume and less development of light.

In order to represent to ourselves the greatest contrast in respect to abundance or paucity of stars, we must take regions widely removed from each other. The maximum of accumulation and the greatest brilliancy are to be found

between the prow of the Ship and Sagittarius; or, to speak more exactly, between the Altar, the tail of the Scorpion, the hand and bow of Sagittarius, and the right foot of Ophiuchus. "No region of the heavens is fuller of objects, beautiful and remarkable in themselves, and rendered still more so by their association and grouping." (254) Next in richness to this beautiful part of the southern celestial vault, is the pleasing and well-starred region in our northern heavens in Aquila and Cygnus, where the Milky Way divides into branches. As the Milky Way is most narrow below the foot of the Southern Cross, so, on the other hand, the region of minimum brightness (where the galaxy is comparatively desert) is in the vicinity of the Unicorn and of Perseus.

The magnificent effect of the Milky Way in the southern hemisphere is enhanced by the circumstance, that between the star $\eta$ Argûs, which has become so celebrated on account of its variability, and $\alpha$ Crucis, it is intersected, in the parallels of 59° and 60° S. Latitude, at an angle of 20°, by the remarkable zone of very large and probably very near stars, to which the constellations of Orion, Canis Major, Scorpio, Centaurus, and Crux belong. A great circle, passing through $\epsilon$ Orionis and the foot of the Cross, indicates the direction of this remarkable zone. The (I might almost say) picturesque effect of the Milky Way is heightened in both hemispheres by its repeated divisions or branchings. For about two-fifths of its length it remains undivided. In the greatest bifurcation the branches divide, according to Sir John Herschel, at $\alpha$ Centauri, (255) not at $\beta$ Centauri as our star-maps represent, nor at the Altar as was stated by Ptolemy (256) : they reunite in Cygnus.

In order to afford a general view of the course and di-

rection of the Milky Way, together with its subordinate branches, I subjoin a very brief and compressed account of its parts, following their order of Right Ascension. Passing through $\gamma$ and $\epsilon$ Cassiopeiæ, the Milky Way sends out to the southward, towards $\epsilon$ Persei, a branch, which loses itself near the Pleiades and Hyades. The main stream, which is here very faint, passes over the three remarkable stars called the Hœdi, in Auriga, between the feet of Gemini and the horns of Taurus,—where it intersects the Ecliptic nearly at the summer solstice,—and thence over the club of Orion, cutting the equinoctial (in 1800), at 6h. 54m. R. A., in the neck of Monoceros :—from this place it increases considerably in brightness. At the after-part of the Ship a branch detaches itself towards the south, proceeding as far as $\gamma$ Argûs, where it breaks off suddenly. The main course continues to 33° South Declination, where, having opened out into a fan-like shape 20° wide, it breaks off; so that, in the line between $\gamma$ and $\lambda$ Argûs, there is a wide gap in the Milky Way. After this it resumes its course, at first with a similar expansion in breadth; but near the hind feet of the Centaur it narrows again, and before entering the constellation of the Cross it reaches its narrowest part, which is only 3° or 4° wide. Soon afterwards the shining Way spreads out into a bright and broad mass, which includes $\beta$ Centauri as well as $\alpha$ and $\beta$ Crucis, and in the middle of which the black pear-shaped coal-bag or coal-sack, which I have spoken of more particularly in the 7th section, is situated. It is in this remarkable region, a little below the coal-sack, that the Milky Way approaches nearest to the South Pole.

The principal division of the Milky Way, alluded to

above, takes place at $\alpha$ Centauri: it is a bifurcation which, according to older views, continues to the constellation of Cygnus. Proceeding from $\alpha$ Centauri, a narrow branch goes northwards towards the constellation Lupus, where it loses itself: then a division shows itself at $\gamma$ Normæ. The northern branch runs into irregular shapes until near the feet of Ophiuchus, where it entirely disappears; the southern branch now becomes the main stream, and passes through the Altar and the tail of the Scorpion to the bow of Sagittarius, where it cuts the Ecliptic in 276° longitude. Further on we recognise it still, but in an interrupted patchy form, passing through Aquila, Sagitta, and Vulpecula, to Cygnus. Here begins a very irregular district, where, between $\epsilon$, $\alpha$, and $\gamma$ Cygni, there is a broad dark space, which Sir John Herschel (257) compares to the coal-sack in the Southern Cross, and which forms, as it were, a centre whence three partial streams diverge. One of these, which has most strength of light, may be pursued in, as it were, a retrograde course past $\beta$ Cygni and $s$ Aquilæ: it does not however unite with the branch before spoken of, which goes to the foot of Ophiuchus. There is still a considerable additional piece of the Milky Way, which extends from the head of Cepheus, and therefore in the vicinity of Cassiopeia, from which constellation we began our description, to Ursus Minor and the North Pole.

From the extraordinary improvement which, by the application of large telescopes, has gradually been made in the knowledge of the sidereal contents, and the differences in respect to concentration of light, in different parts of the Milky Way, views of merely optical projection have been replaced by what may rather be deemed views of physical character and

formation. Thomas Wright of Durham, (258) Kant, Lambert, and at first also William Herschel, were inclined to regard the form of the Milky Way, and the apparent accumulation of stars in it, as consequences of the flattened form and unequal dimensions of the "world-island" (sidereal stratum) in which our solar system is included. The hypothesis of equal magnitude and equable distribution of fixed stars has recently been shaken on many sides. The bold and able investigator of the heavens, William Herschel, declared himself, in his last work, (259) decidedly in favour of the assumption of a ring or annulus of stars,—which assumption he had combated in a treatise in the year 1784. Recent observations have favoured the hypothesis of a system of detached concentric rings. The thickness of these rings appears to be very unequal, and the several strata whose united stronger or fainter light we receive, are doubtless situated at very different heights, *i. e.* very different distances from us: but the relative brightness of the several stars, which we estimate as being from the 10th to the 16th magnitude, cannot be regarded as such a measure of their relative distances, as could enable us to derive from thence a satisfactory numerical (260) determination of the radii of the respective spheres of distance.

In many parts of the Milky Way, the space-penetrating power of instruments is sufficient to resolve the star-clouds, and to enable us to see single luminous points projected on the dark starless regions of celestial space. In such case we really look through into free and open space. "It leads us," says Sir John Herschel, "irresistibly to the conclusion, that in these regions we see *fairly through* the starry stratum." (261) In other regions we see, as through openings and fissures,

either distant world-islands, or out-branching parts of the annular system; in others, again, the Milky Way has hitherto remained "fathomless," even to the 40-feet telescope. (262) Investigations respecting differences in the intensity of light in the Milky Way, as well respecting the magnitudes of stars, and their regular increase in numbers from the poles of the galaxy to the galactic circle itself, (an increase which is particularly remarked for 30° on either side of the Milky Way in stars below the 11th magnitude, (263) and therefore in $\frac{16}{17}$ths of the whole number), have conducted those who have been engaged in the most recent researches in the southern heavens, to remarkable views and probable results in regard to the form of the galactic annular system, and to what has been boldly called the place of our Sun in the world-island to which that annular system belongs. The place assigned to the Sun is excentric, and conjectured to be where a subordinate stratum branches off from the principal ring, (264) in one of the comparatively desert regions, and nearer to the Southern Cross than to the opposite galactic node. (265) The depth to which our system is immersed in the star-stratum which forms the Milky Way (reckoned from the southern limit) is supposed to be equal to the distance, (or to the light-path) of stars of the 9th and 10th, but not of the 11th magnitude. (266) Where, from the peculiar nature of particular problems, measurements and immediate cognizance by the senses fail, we view, as it were by an imperfect twilight, the results which intellectual contemplation aspires to attain.

# IV.

NEWLY-APPEARED AND VANISHED STARS.—VARIABLE STARS, WHICH HAVE MEASURED AND RECURRING PERIODS.—VARIATIONS OF THE INTENSITY OF LIGHT IN CELESTIAL BODIES OF WHICH THE PERIODICITY HAS NOT YET BEEN INVESTIGATED.

The appearance of previously unseen stars in the celestial vault, especially the sudden appearance of strongly scintillating stars of the 1st magnitude, is an event in the regions of space of which the occurrence has ever excited the astonishment of men. This astonishment is so much the greater, as such an event in Nature as the sudden visibility of an object which, though previously unseen, we yet believe to have existed previously, is one of the rarest of all phænomena. In the course of the three centuries from 1500 to 1800, there have appeared to the inhabitants of the northern hemisphere 42 comets visible to the naked eye,—being, on an average, 14 in a century; while, during the same three hundred years, only 8 new stars have been observed. The rarity of the latter occurrence becomes still more striking when we embrace yet longer periods. From the important epoch in the history of astronomy of the completion of the Alphonsine Tables, to the time of William Herschel, or from 1252 to 1800, we

reckon, of comets visible to the naked eye, about 63, and of new stars only 9; thus, for the period within which, in European civilised countries, we can count on a tolerably accurate enumeration, we find the proportion of new stars to comets, both being visible to the naked eye, as 1 to 7. We shall soon show, that if in the Chinese registers of Ma-tuan-lin, we carefully distinguish the observations of newly-appeared stars from those of tail-less comets,—and if we go back to a century and a half before the Christian era,—we find that, in the course of almost 2000 years, 20 or 22 of such phænomena are the utmost that can be adduced with any degree of certainty.

Before proceeding to general considerations, I prefer, by dwelling on a single example, and by the narration of an eye-witness, to attempt to convey to my readers a just idea of the vividness of the impression produced by the appearance of a new star. "When," says Tycho Brahe, "I was returning to the Danish Islands, after travelling in Germany, I remained awhile (ut aulicæ vitæ fastidium lenirem) with my uncle, Steno Bille, at the pleasantly-situated former convent of Herritzwadt, where I was in the habit of only quitting my chemical laboratory in the evening. On coming forth into the open air, and raising my eyes as usual to the well-known heavenly vault, I saw, with indescribable astonishment, near the zenith, in Cassiopeia, a radiant fixed star of a magnitude never before seen. In the excitement, I thought I could not trust my senses. In order to convince myself that it was no illusion, and to collect the testimony of others, I called my workman from the laboratory, and asked all the country people who were passing by, whether they saw the new suddenly-outshining bright star as I did. Subsequently

I learned that in Germany, waggoners, and 'other common people,' first called the attention of astronomers to this great celestial phænomenon, which (as in the case of comets appearing without having been predicted) renewed the usual scoffs at learned men."

"I found this new star," Tycho Brahe continues, "without any tail, not surrounded by any nebulous appearance, and perfectly similar in all respects to all the other fixed stars, but sparkling still more brightly than those of the 1st magnitude. It exceeded in brilliancy Sirius, α Lyræ, and Jupiter, and could only be paralleled by the brightness of Venus when she is nearest the Earth, (at which time only her fourth part is illuminated). When the atmosphere was clear, men gifted with keen sight could distinguish the new star in the day-time, and even at noon. At night, when the sky has been so far covered that all other stars were veiled, it has repeatedly been seen through clouds of moderate density (nubes non admodum densas). Distances from other neighbouring stars in Cassiopeia, which I measured with great care throughout the whole of the following year, convinced me of its perfect immobility. In December 1572, the light of the star began to diminish: it soon became equal to Jupiter; and in January 1573 it was less bright than that planet. Continued photometric estimations gave, in February and March, an equality with the stars of the 1st magnitude (stellarum affixarum primi honoris; for Tycho Brahe seems determined never to use the expression of Manilius, stellæ fixæ); for April and May, light equal to stars of the 2d; for July and August, of the 3d; and for October and November, of the 4th magnitude. About the month of November, the new star was no brighter than

the eleventh star in the lower part of Cassiopeia's chair. From December 1573 to February 1574, it diminished successively to the 5th and 6th magnitudes. In the following month, after shining for seventeen months, the new star disappeared altogether, leaving no trace visible to the naked eye." (The telescope was invented thirty-seven years later.)

It appears, then, that the loss of light in this star was exceedingly gradual and regular, and not interrupted by periods of renewed or fresh increase of light, (as has been several times the case in our own days with $\eta$ Argûs, which, indeed, is not to be called a new star). In the star in Cassiopeia, of which we have been speaking, there was alteration of colour as well as of light,—a circumstance which has since given occasion to many erroneous conclusions respecting the velocity of coloured rays in traversing space. When it first appeared, and as long as it equalled first Venus and then Jupiter in brightness, its light was, during two months, white; after which it passed through yellow into red. In the spring of 1573, Tycho Brahe compared it to Mars; he next found it *almost* comparable to the star in the right shoulder of Orion (Betelgeuze). Its colour resembled most nearly the red colour of Aldebaran. In the spring of 1573, particularly in the month of May, the whiteness returned (albedinem quandam sublividam induebat, qualis Saturni stellæ subesse videtur). In January 1574 it still continued to be of the 5th magnitude and white, but of a duller white, and with a degree of scintillation strikingly great in proportion to its feeble light, until its entire gradual disappearance in the month of March, 1574.

The detailed character of these statements (267) would of itself suffice to show how great a stimulus to the consideration of highly important questions must have been afforded, by the occurrence of such a phenomenon at a period so brilliant in the history of astronomy. The stimulus was the stronger, because, notwithstanding the above-described general rarity of the appearance of new stars, it happened that European astronomers witnessed phænomena of this kind three times within the short period of thirty-two years. The importance of star-catalogues, determining with certainty the novelty of such stars, was more and more recognised; their periodical character, *i. e.* their reappearance after the lapse of several centuries, was discussed; (268) and Tycho Brahe even boldly put forth a theory respecting the process of formation of stars from cosmical vapour or nebulosity, which had much analogy with that of the great William Herschel. He believed that the nebulous celestial matter, luminous in the course of its condensation, solidified into fixed stars:—"Cœli materiem tenuissimam, ubique nostro visui et planetarum circuitibus perviam, in unum globum condensatam, stellam effingere." He conceived this everywhere-diffused celestial matter to have already a certain degree of condensation in the Milky Way, where its dawning luminosity produced a mild silvery brightness,—and this he thought the reason why the new star, like those of 945 and 1264, shone forth on the edge of the Milky Way itself (quo factum est quod nova stella in ipso Galaxiæ margine constiterit); and it even seemed possible to recognise the place (the opening, hiatus) from whence the nebulous matter of the Milky Way had been taken. (269) All this reminds us of the transition of cosmical vapour into clusters of stars,—

of the concentration to a central nucleus,—and of the hypotheses respecting the gradual development of solid celestial bodies from a vaporous fluid,—which gained acceptance at the commencement of the present century; but which now, according to the ever-varying fluctuations of the world of thought, have become subject to fresh doubts.

We may, with more or less certainty, reckon among the new "temporary" stars the following, which I have arranged in the order of their first shining forth:—

| | | | |
|---|---|---|---|
| *a* | 134 | B.C. | in Scorpio. |
| *b* | 123 | A.D. | in Ophiuchus. |
| *c* | 173 | — | in Centaurus. |
| *d* | 369? | — | |
| *e* | 386 | — | in Sagittarius. |
| *f* | 389 | — | in Aquila. |
| *g* | 393 | — | in Scorpio. |
| *h* | 827? | — | in Scorpio. |
| *i* | 945 | — | between Cepheus and Cassiopeia. |
| *k* | 1012 | — | in Aries. |
| *l* | 1203 | — | in Scorpio. |
| *m* | 1230 | — | in Ophiuchus. |
| *n* | 1264 | — | between Cepheus and Cassiopeia. |
| *o* | 1572 | — | in Cassiopeia. |
| *p* | 1578 | — | |
| *q* | 1584 | — | in Scorpio. |
| *r* | 1600 | — | in Cygnus. |
| *s* | 1604 | — | in Ophiuchus. |
| *t* | 1609 | — | |
| *u* | 1670 | — | in Vulpes. |
| *v* | 1848 | — | in Ophiuchus. |

*Elucidatory Notices of the above Temporary Stars.*

*a.* Which first appeared between $\beta$ and $\rho$ Scorpii, in the month of July, 134 years before our Era, is recorded in the Chinese Notices of Ma-tuan-lin, for the knowledge of which we are indebted to the philological learning of Edouard Biot (Connaissance des Temps pour l'an 1846, p. 61). The "extraordinary" stars of "strange or foreign appearance" of these Chinese Notices,—called also "guest-stars" ("étoiles hôtes," "ke-sing," as it were foreigners of strange physiognomy), and from which the observers themselves had distinguished and separated comets with tails,—included, it is true, some tail-less comets, as well as non-moving new stars, properly so-called; but an important though not infallible criterion was implied by the assignment of motion in some cases (ke-sing of 1092, 1181, and 1458), and its non-assignment in others, as well as in the occasional addition of the remark—"the Ke-sing dissolved" (disappeared). We may also recal here the faint, never sparkling, always mild light of the heads of comets, whether with or without tails, whereas the Chinese "extraordinary stars" are compared, in respect to the intensity of their light, to Venus, which does not at all suit the character of comets, and more especially of tail-less comets. The star we are now speaking of (*a*, 134 B.C.), which appeared under the old dynasty of Han, may, as Sir John Herschel remarks, have been the new star of Hipparchus, which, according to Pliny's account, induced him to draw up his list of stars. Delambre twice calls this account "a fable,"—"une historiette" (Hist. de l'Astr. anc. T. i. p. 290; and Hist.

de l'Astr. mod. T. i. p. 186). As, however, according to Ptolemy's express statement (Almag. vii. 2, p. 13, Halma), Hipparchus's star-list is connected with the year 128 B.C.; and Hipparchus, as I have already said elsewhere, observed in Rhodes, and perhaps also at Alexandria, between 162 and 127 B.C., there is at least nothing to contradict the conjecture: it is very conceivable that the great astronomer of Nicea might have observed much before the time when he may have been led to propose to himself the preparation of an actual catalogue. Pliny's expression—"suo ævo genita," refers to his whole life. When Tycho Brahe's star appeared, in 1572, the question was much debated whether it should be regarded as belonging to the class of new stars or to that of comets without tails. Tycho Brahe himself was of the first opinion (Progymn. p. 319—325). The words "ejusque *motu* ad dubitationem adductus" might, indeed, lead us to think of a faint or tail-less comet, but the rhetorical style of Pliny permits every degree of indefiniteness in expression.

*b*. Appeared between α Herculis and α Ophiuchi, in December, A.D. 123, according to the Chinese notice, extracted by Edouard Biot from Ma-tuan-lin. (A new star is also said to have appeared under Hadrian, in 130. A.D.)

*c*. A singular very large star. The notices of this and of the three following stars are also taken from Ma-tuan-lin. It appeared on the 10th of December, A.D. 173, between α and β Centauri, and disappeared at the end of eight months, having shown the five different colours one after another;—Edouard Biot says, in his translation

"successively" ("successivement"). Such an expression might almost lead us to infer a series of colours like those of the Tychonian Star before spoken of; but Sir John Herschel (I believe more correctly) regards it as a description of coloured scintillation (Outlines, p. 563), as Arago has interpreted an almost similar expression of Kepler's, relatively to the new star, in 1604, in Ophiuchus (Annuaire pour 1842, p. 347).

*d.* Shone from March to August, 369.

*e.* Between λ and φ in Sagittarius. In the Chinese Notices it is expressly remarked — "where the star remained without motion from April to July, 386."

*f.* A new star near α Aquilæ shone forth in the time of the Emperor Honorius in 389, with the brightness of Venus, as is related by Cuspinianus: three weeks afterwards it disappeared without leaving any trace. (270)

*g.* March, 393 in the tail of the Scorpion; from Ma-tuan-lin's notices.

*h.* The year 827 is doubtful; what is more certain is the epoch of the first half of the 9th century, in which, under the government of the Caliph Al-Mamun, the two celebrated Arabian Astronomers Haly, and Giafar Ben-Mohammed Albumazar, observed at Babylon a new star whose light is said "to have equalled that of the moon in her quarters!" This cosmical event also belongs to the constellation of Scorpio. The star disappeared after an interval of only four months.

*i.* The appearance of this star, which is said to have shone forth in the reign of the Emperor Otho the Great in the year 945, as well as that of the star of 1264, both

rest solely on the testimony of the Bohemian astronomer Cyprianus Leovitius, who declares that he took the information from a manuscript chronicle, and who calls attention to the circumstance that both phenomena (in the years 945 and 1264) took place between the constellations of Cepheus and Cassiopeia, quite close to the Milky Way, and at the very place where the Tychonian star appeared in 1572. Tycho Brahe (Progymn. p. 331 and 709), defends the trustworthiness of Cyprianus Leovitius against Pontanus and Camerarius, who surmised a confusion with long-tailed comets.

*k*. According to the testimony of the monk of St. Galle, Hepidannus, (who died in the year 1088, and whose annals extend from 709 to 1044), a new star, of unusual magnitude and dazzling brightness (oculos verberans), was seen in the most southern part of the heavens in the sign of Aries: it appeared near the end of the month of May 1012, and contiuued to shine for three months. It varied in a wonderful manner, sometimes appearing larger, sometimes smaller, and sometimes not being seen at all. "Nova stella apparuit insolitæ magnitudinis, aspectu fulgurans, et oculos verberans non sine terrore. Quæ mirum in modum aliquando contractior, aliquando diffusior, etiam extinguebatur interdum. Visa est autem per tres menses in intimis finibus Austri, ultra omnia signa quæ videntur in cœlo," (see Hepidanni, Annales breves, in Duchesne, Historiæ Francorum Scriptores, T. iii. 1641, p. 477; compare also Schnurrer, Chronik der Seuchen, Th. I. S. 201. More recent historical criticism has, however, preferred to the manuscript used by Duchesne and Goldast, which places the phenomenon in 1012,

another which gives a difference of dates, placing it six years earlier, or in 1006, (see Annales Sangallenses majores in Pertz, Monumenta Germaniæ historica Scriptorum, T. i. 1826, p. 81). The authorship of the supposed writings of Hepidannus has also been rendered doubtful by recent investigations. The strange phenomenon of variability has been called by Chladni the "conflagration and destruction of a fixed star." Hind, (Notices of the Astron. Soc. Vol. viii. 1848, p. 156) conjectures, that the star of Hepidannus may be identical with the star which Ma-tuan-lin marks as having been seen in China in February 1011, in Sagittarius, between $\sigma$ and $\phi$. But in such case Ma-tuan-lin must have been mistaken not only in the year, but also in the constellation in which the star appeared.

*l.* End of July 1203, in the tail of the Scorpion. According to the Chinese notice, " a new star of a blueish white light, without any luminous nebulosity, resembling Saturn (Edouard Biot, in the Connaissance des temps pour 1846, p. 68).

*m.* Another Chinese observation from Ma-tuan-lin, whose astronomical Notices, with the exact indication of the positions of the comets and fixed stars, reascend to 613 years B. C., or to the time of Thales and the Expedition of Colæus of Samos. The new star appeared in the middle of December, 1230, between Ophiuchus and the serpent. It "dissolved away" at the end of March 1231.

*n.* Is the star whose appearance in 1264 is mentioned by the Bohemian astronomer, Cyprianus Leovitius, (see the star previously referred to, *i,* 945). At the same

time (July 1264) there appeared a great comet, whose tail extended over half the sky, and which therefore could not be confounded with the star described as having shone forth between Cepheus and Cassiopeia.

*o*. The star of Tycho Brahe, of the 11th of November 1572, in Cassiopeia's chair; R. A. 3° 26′; Decl. 63° 3′ (for 1800).

*p*. February 1578, from Ma-tuan-lin. The constellation in which the star appeared is not given; but the intensity and radiation of its light must have been extraordinary, since the Chinese notice has appended to it a note, saying "a star as great as the sun!"

*q*. 1st of July 1584, not far from π Scorpii; a Chinese observation.

*r*. The star 34 Cygni, according to Bayer. Wilhelm Janson, the distinguished geographer, who for some time observed with Tycho Brahe, first had his attention arrested by the new star in the breast of the Swan, (at the commencement of the neck), as an inscription upon his celestial globe testifies. Kepler being prevented, both by his journeys and by the want of instruments after Tycho Brahe's death, did not begin to observe it until two years later, and (which is the more surprising, as the star was of the 3rd magnitude) he even was not until then aware of its existence. He says: "Cum mense Majo anni 1902 primum litteris monerer de novo Cygni phænomeno . . ." (Kepler de Stella nova tertii honoris in Cygno 1606, appended to the work de stella nova in Serpent, p. 152, 154, 164, and 167). In Kepler's memoir it is never said (as it has often been in more modern writings) that the star in the Swan, on its first appearance,

was of the 1st magnitude. Kepler even calls it parva Cygni stella, and everywhere describes it as of the 3rd magnitude. He determines its position in R. A. 300°46′; Decl. 36°52′: (therefore for 1800) R. A. 302°36′; Decl. + 37°27′). The star decreased in brightness, especially after 1619, and disappeared in 1621. Dominique Cassini (see Jacques Cassini, Elémens d'Astr. p. 69) saw it again attain the 3rd magnitude in 1655, and then disappear. Hevelius observed it again in November 1665: at first very small, then larger, but without reattaining the 3rd magnitude. Between 1677 and 1682 it was already only of the 6th magnitude, and so it has remained. Sir John Herschel places it in the list of "variable" stars, but Argelander does not.

*s*. Next to the star in Cassiopeia, in 1572, the new star which has gained the greatest celebrity is that which appeared in Ophiuchus in 1604. (R. A. 259° 42′, and South Decl. 21° 15′ for 1800). With each of these two stars a great name is connected. The star in the right foot of Ophiuchus was first seen, not by Kepler himself but by his pupil, the Bohemian John Brunowski, on the 10th of October 1604; being then "brighter than any star of the first magnitude, larger than Jupiter and Saturn, but not so large as Venus." Herlicius claims to have observed it on the 27th of September. Its brightness was inferior to that of the Tychonian star of 1572, nor was it seen, like the latter, in the day-time; but its scintillation was much stronger, and especially excited the astonishment of all observers. As sparkling is always connected with dispersion of colour, much is said of its coloured and continually changing light. Arago (Annuaire

pour 1834, p. 299-301; and Ann. pour 1842, p. 345-347), has already called attention to the fact, that Kepler's star did not change colour after long intervals like the Tychonian star, which was first white, then yellow, red, and again white. Kepler says decidedly, that his star, as soon as it had risen above terrestrial vapours, was white. If he speaks of the colours of the rainbow, it is in order to give a clear idea of the coloured scintillation,—"exemplo adamantis multanguli, qui Solis radios inter convertendum ad spectantium oculos variabili fulgore revibraret, colores Iridis (stella nova in Ophiucho) successive vibratu *continuo* reciprocabat." (De Nova Stella Serpent., p. 5 and 125.) In the beginning of January 1605, the star was still brighter than Antares, but not so bright as Arcturus. At the end of March of the same year it was described as of the 3rd magnitude. The proximity of the sun prevented all observations for four months. Between February and March 1606 it disappeared, without leaving any trace. The inaccurate observations of the "great changes of position of the new star" of Scipio Claramontius and the geographer Blaeu or Blaew, as Jacques Cassini has already remarked (Elém. d'Astron. p. 65), scarcely deserve to be mentioned, as they have been refuted by the more certain observations of Kepler. The Chinese notices of Ma-tuan-lin speak of a phenomenon which, in point of time and of position, has some resemblance to the appearance of the new star in Ophiuchus. On the 30th of September, 1604, there was seen in China, not far from $\pi$ Scorpii, a reddish yellow (globe-large) star. It shone in the South West until November of the same year, when it became invisible. It appeared on the 14th of January, 1605, in the

South East, but "darkened" a little in March 1606. (Connaissance des temps pour 1846, p. 59). The locality, $\pi$ Scorpii, might easily have been confounded with the foot of Ophiuchus, but the expressions South West and South East, the reappearance, and the circumstance of no mention being made of the final complete disappearance of the star, leave the identity doubtful.

*t.* Also from Ma-tuan-lin's notices: a star of considerable magnitude, seen in the South West; all more circumstantial details are wanting.

*u.* Discovered by the Carthusian Monk Anthelme, on the 20th of June, 1670, in the head of Vulpes (R. A. 294° 27′; Decl. 26° 47′), not far from $\beta$ Cygni. When it first shone out it was not of the 1st but of the 3rd magnitude. It disappeared at the end of three months, but shewed itself on the 17th of March, 1671, being then of the 4th magnitude. Dominique Cassini observed it diligently in April 1671, and found its light very variable. The new star was expected to have returned to its original brightness at the end of about ten months, but it was sought in vain in February 1672, and did not appear until the 29th of March in that year, and then only of the 6th magnitude, and has never been seen since. (Jacques Cassini, Elémens d'Astronomie, p. 69-71.) These phenomena induced Dominique Cassini to seek for stars never before seen (by him!). He states that he found 14 such stars, of the 4th, 5th, and 6th magnitudes (8 in Cassiopeia, 2 in Eridanus, and 4 near the North Pole). From the absence of precisely assigned positions, and as, moreover, like those found by Maraldi between 1694 and 1709, they are in other respects more than

doubtful, I do not include them in the present list. (Jacques Cassini, Elém. d'Astron. p. 73-77; Delambre, Hist. de l'Astr. mod. T. ii. p. 780.)

*v.* Since the appearance of the new star in Vulpes, 178 years had passed without any similar phenomenon having presented itself, although in this long interval the heavens had been most carefully examined by the combination of a more diligent use of telescopes, and comparison with improved star-catalogues. On the 28th of April, 1848, in the private Observatory of Mr. Bishop (South Villa, Regent's Park), Mr. Hind made the important discovery of a new star of the 5th magnitude in Ophiuchus, of a reddish yellow colour: R. A. 16h. 50m. 59s.; South Decl. 12° 39′ 16″ for 1848. In the case of no other newly-appeared star have the novelty of the phenomenon and the invariability of position been more certainly and accurately shown. It is now (1850) barely of the 11th magnitude, and, according to Lichtenberg's diligent observation, is probably near its time of vanishing. (Notices of the Astr. Soc. Vol. viii. pp. 146 and 155-158.)

The above enumeration and description of new stars which have appeared and disappeared within the last 2000 years are perhaps somewhat more complete than any which have been given previously. It may justify some general considerations. We distinguish three kinds of phenomena:—new stars, which suddenly shine forth, and vanish again after a greater or less interval of time;—stars whose brightness is subject to an already determinable periodical variability;—and stars which, like $\eta$ Argûs, show at once an extraordinarily increasing and an irregularly varying brightness. All these

three phenomena are probably intimately allied. The new star in Cygnus (1600), which, after entirely disappearing, (to the unassisted eye, it must be remembered), reappeared and remained as a star of the 6th magnitude, leads us to recognise the affinity between the two first kinds of celestial phenomena. The celebrated Tychonian star of 1572 was believed, while its light still shone, to be identical with the new star of 945 and 1264. The period of 300 years surmised by Goodricke (the intervals between the epochs of the phenomena, which are perhaps not very certain, are 319 and 308 years), is reduced by Keill and Pigott to 150 years. Arago (271) has shewn how improbable it is that Tycho Brahe's star (1572) should belong to the class of periodically varying stars. Nothing as yet would appear to justify our regarding *all* newly appeared stars as variable in periods of long, and therefore unknown, duration. If, for example, we regard the self-luminosity of all the suns in the firmament as the results of electro-magnetic processes in their respective photospheres, we may (without assuming local and temporary condensations of the "celestial air," or the intervention of cosmical clouds) imagine this luminous process to take place in various manners, either once only or periodically, and either regularly or irregularly in respect to the time of recurrence. The electric luminous processes of our terrestrial globe, whether presenting themselves to us as thunderstorms in the atmosphere, or as polar effluxes, with much seemingly irregular variability, do yet often shew also a certain periodicity dependent on the seasons of the year and the hours of the day. We may even often trace this periodicity in the formation, for several successive days, and in an otherwise perfectly serene sky, of small clouds at the same

part of the heavens, as is shewn by the frequently recurring failure in observations of the culmination of particular stars.

The circumstance that almost all have shone forth at first with great intensity of light as stars of the first magnitude, and even scintillating more brilliantly, and that they are not seen (by the naked eye at least) to increase gradually in brightness, appear to me peculiarities well deserving of regard. Kepler (272) attended so much to this as a criterion, that he confuted the vain pretension of Antonius Laurentinus Politianus, who claimed to have seen the star in Ophiuchus (1604) before it had been seen by Brunowski, by the fact of Laurentinus having said—"Apparuit nova stella parva, et postea de die in diem crescendo apparuit lumine non multo inferior Venere, superior Jove." Only three stars are known (and these may be viewed, therefore, as exceptional instances) which did not shine forth at first as stars of the first magnitude: viz. two of the 3rd magnitude, one in Cygnus in 1600, and one in Vulpes in 1670; and Hind's new star of the 5th magnitude in Ophiuchus in 1848.

It is much to be regretted, as we have already remarked, that in the long interval of 178 years which have elapsed since the invention of the telescope, only 2 new stars have been seen; whereas these phenomena have been sometimes so comparatively frequent, that at the close of the fourth century 4 took place in 24 years, in the thirteenth century 3 in 61 years, and at the end of the sixteenth and beginning of the seventeenth centuries (in the period of Kepler and Tycho Brahe), 6 were observed in 37 years. In all these numerical statements I take into account the Chinese observations of "extraordinary stars," the greater part of which are regarded by our most distinguished astronomers as

worthy of confidence. If the question be asked why, among the new stars which have been seen in Europe, that of Kepler in Ophiucus may possibly be indicated in Ma-tuan-lin's notices, but that of Tycho Brahe in Cassiopeia (1572) certainly is not so, I can no more explain the reason of such a circumstance as an isolated fact, than I can explain, for example, why the great luminous phænomenon seen in China in February 1578 is not mentioned by European observers of that period. The difference of longitude (114°) could only explain invisibility in a few cases. Those who have occupied themselves with similar inquiries know that the circumstance of events, either in politics or in nature, either on the earth or in the skies, not being noticed, is not always a proof of their not having occurred; and if we compare together the three different Chinese lists of stars in Ma-tuan-lin, we shall also find that comets (*ex. gr.* those of 1385 and 1495) which are contained in the one list are wanting in the others.

Older astronomers, Tycho Brahe and Kepler, as well as modern ones, Sir John Herschel and Mr. Hind, have called attention to the circumstance, that by far the greater number (I find four-fifths) of all the new stars which have been described either in Europe or in China have appeared in or near the Milky Way. If, as is more than probable, the mild nebulous light of the annular sidereal strata of the galaxy proceeds solely from a simple aggregation of telescopic stars, Tycho Brahe's hypothesis of the formation of new fixed stars by a globular condensation of the celestial vapour falls to the ground. What may be effected by forces or powers of attraction in crowded sidereal strata or star-clusters, supposing them to rotate round central nuclei,

cannot be here determined, and belongs rather to the mythical department of Astrognosy. Of the 21 new stars enumerated in the list above given, 5 (those of 134, 393, 827, 1203, and1584) appeared in the constellation Scorpius; 3 (those of 945, 1264, and 1572) in Cassiopeia and Cepheus; and 4 (those of 123, 1230, 1604, and 1848) in Ophiuchus. On one occasion, however, a new star (that of the Monk of St. Galle in 1012) appeared very far from the Milky Way, or in Aries. Kepler himself, who considered the star which Fabricius described as shining forth in the neck of the Whale in 1596, and as having disappeared from view in October of the same year, to be really a new star, yet gives its position as a reason to the contrary. (Kepler de Stella Nova Serp. p. 112.) Ought the comparative frequency of these phænomena in the same constellations to lead us to infer that, in certain directions in space, for example, in those in which we see the stars of Scorpius and Cassiopeia, the conditions of this kindling or beaming forth are peculiarly favoured by local conditions or relations? Are there situated in these directions rather than in any others such celestial bodies as are peculiarly adapted for explosive luminous processes of short duration?

The luminosity was briefest in the stars of the years 389, 827, and 1012. In the star corresponding to the first of these dates it lasted 3 weeks, in the second 4 weeks, and in the third 3 months. On the other hand, Tycho Brahe's star in Cassiopeia shone for 17 months, and Kepler's in Cygnus (1600) was fully 21 years before it disappeared. It reappeared in 1655, being then, as on its first appearance, of the 3rd magnitude, whence it declined to the 6th; but,

according to Argelander's observations, it is not to be ranked in the class of periodically variable stars.

The careful consideration and enumeration of *vanished* stars, or stars which are supposed to have disappeared, are important in respect to the research for the great number of small planets which are probably belonging to our solar system; but notwithstanding the exactness of the modern registration of telescopic fixed stars, and of our modern star-maps, very great care is still required for the attainment of full certainty and conviction, that any particular star has actually disappeared from the heavens within any definite period. Errors of observation, of reduction, or of the press,(273) often disfigure the best catalogues. The disappearance of a celestial body from the place where it had certainly been seen before, may be occasioned either by its having moved from thence, or by the luminous process on its surface or in its photosphere being so far enfeebled, that the luminous undulations no longer sufficiently stimulate our visual organs. What we no longer see has not on that account ceased to exist. The idea of the "destruction" or the "burning out" of stars which are gradually becoming invisible, belongs to the Tychonian period. Pliny also, in the fine passage upon Hipparchus, asks: "Stellæ an obirent nascerenturve?" The continual apparent change in the Universe, such as the disappearance of what was before seen, is not annihilation, but only the transition of material substances into new forms, or into compositions dependent on new processes. Dark cosmical bodies may suddenly shine forth afresh by a renewed luminous process.

Since all is in motion in the celestial canopy, and all things are variable in space and in time, we are led by analogy to conjecture, that as the fixed stars have all not merely an apparent motion, but also a proper motion of their own,—so also their surfaces or luminous atmospheres may be generally subject to changes, which, in the case of the greater number of these cosmical bodies, may occur in exceedingly long, and therefore unmeasured, and perhaps indeterminable, periods; while, in the case of a few, they may take place without being periodical, as by a sudden revolution, and for a longer or shorter continuance. The latter class of phænomena, of which a remarkable example is presented in our own days by a large star in the Ship ($\eta$ Argûs), will not be discussed in this place, where we are about to consider only stars variable within periods which have already been investigated and measured. It is important to distinguish from each other three great sidereal phænomena, of which the connection has not yet been recognised: viz. variable stars of known periodicity; the blazing forth of what are called new stars; and sudden changes of light in long-known fixed stars, which had previously always shewn a uniform intensity. I propose at present to dwell exclusively on the first-named form of variability, of which the earliest accurately observed example (1638) is furnished by Mira Ceti, a star in the neck of the Whale. David Fabricius, a minister of the church in East Friesland, and the father of the discoverer of the solar spots, had, it is true, already observed this star as of the 3rd magnitude, on the 13th of August, 1596, and had noticed its disappearance in October of the same year. But the alternately recurring change of light, or the periodical variability of the star, was not discovered until

forty-two years later, by a Professor of Franeker, Johann Phocylides Holwarda. This discovery was followed in the same century by that of two other variable stars: $\beta$ Persei (1669), described by Montanari, and $\chi$ Cygni (1687), described by Kirch.

The increased number of stars of this class which have been observed since the beginning of the present century, and the irregularities which have been remarked in their periods, have excited in the highest degree the interest which is taken in this very complicated group of phænomena. From the difficulty of the subject, and my earnest desire that in this work the *numerical elements*, as the most important fruit of all observation, should be given as they are afforded by the most recent investigation, and according to the actual state of our knowledge, I have requested the kind aid of the astronomer who, among our cotemporaries, has devoted himself with the greatest activity and the most brilliant success to the study of periodically varying stars. I laid before my kind friend Argelander, Director of the Astronomical Observatory at Bonn, in the fullest confidence, the doubts and questions to which my own inquiries had given occasion; and I am indebted solely to his manuscript communications for what follows, great part of which has not yet been otherwise published.

The greater number of variable stars are red or reddish, but by no means all. So, for example, besides $\beta$ Persei (Algol in the head of Medusa), $\beta$ Lyræ and $\epsilon$ Aurigæ have also white light. $\eta$ Aquilæ is somewhat yellowish; and so, in a still less degree, is $\zeta$ Geminorum. The statement formerly made, that some variable stars, and particularly Mira Ceti, were redder while their brightness was diminishing than

while it was increasing, appears unfounded. Whether in the double star α Herculis, in which Sir William Hershchel calls the large star red, and Struve calls it yellow and its companion dark-blue, this small companion which is estimated from the 5th to the 7th magnitude, be itself also variable, appears very problematical. Struve ([274]) himself says only "suspicor minorem esse variabilem." Variability is by no means attached to redness of colour. There are many red, and some very red, stars, as Arcturus and Aldebaran, in which, hitherto, no variation has ever been observed; and the existence of any variability in a star in Cepheus (No. 7582 of the Catalogue of the British Association),—which, on account of its extraordinary redness, was called by William Herschel, in 1782, the Garnet—is more than doubtful.

It is difficult to say exactly what ought to be regarded as the whole known number of periodically variable stars, because the periods which have already been deduced are of very unequal degrees of certainty. The two variable stars in Pegasus, as well α Hydræ, ε Aurigæ, and α Cassiopeiæ, have not the same certainty as Mira Ceti, Algol, and δ Cephei. In drawing up a table, therefore, the question arises, what degree of certainty is to be regarded as sufficient. As will be seen in the general table at the close of this investigation, Argelander reckons the number of satisfactorily determined periods at only 24. ([275])

We have seen that the phænomenon of variability belongs to some white stars as well as to red ones, and it is also found to exist in stars of very different magnitudes: for example, in one star of the 1st magnitude, α Orionis; in Mira Ceti, α Hydræ, α Cassiopeiæ, and β Pegasi, all of the 2nd magnitude; β Persei, 2·3 magnitude; and in η Aquilæ and β Lyræ, 3·4 magnitude. There are also, and in much

greater number, variable stars of the 6th to the 9th magnitudes, as the Variabiles, Coronæ, Virginis, Cancri, and Aquarii. The maximum of the star $\chi$ Cygni undergoes great fluctuations.

That variable stars are very irregular in their periods had long been known; but that in the midst of this apparent irregularity their variations are yet subject to definite laws, has for the first time been made out by Argelander. He hopes to demonstrate the truth of his views in this respect in detail in an extensive treatise devoted expressly to the subject. He now considers that two perturbations in the period of $\chi$ Cygni, one of 100 and the other of 8·5 single periods, are more probable than one of 108. Whether such disturbances originate in alterations in the luminous process going on in the atmosphere of the star, or in the period of revolution of a planet revolving round the fixed star or sun $\chi$ Cygni, and affecting the form of its photosphere by attraction, remains indeed still uncertain. The greatest irregularities in the variation of lustre are certainly presented by the star "Variabilis Scuti" in Sobieski's Shield, as this star sometimes diminishes from 5·4m. down to 9m. and once, according to Pigott, disappeared entirely at the end of the last century. At other times its fluctuations have only been between 6·5m. and 6m. The maximum brightness observed in $\chi$ Cygni has varied between 6·7m. and 4m., and that of Mira, between 4m. and 2·1m. On the other hand, $\delta$ Cephei has shewn in the length of its periods an extraordinary degree of regularity, greater than in any other variable star, as has appeared by 87 minima observed between the 10th of October, 1840, and the 8th of January, 1848, and others still more recent. In $\epsilon$ Aurigæ the alteration of brightness, [276] as found by an indefatigable ob-

server, Heis at Aix la Chapelle, is only from the 3·4m. to the 4·5 magnitude.

Mira Ceti shews great differences of maximum brightness: for example, on the 6th of November, 1779, it was only a little inferior to Aldebaran, and it has not infrequently been brighter than stars of the 2nd magnitude; whilst at other times it has not even attained the brightness of $\delta$ Ceti, which is of the 4th magnitude. Its mean brightness is equal to that of $\gamma$ Ceti (3rd magnitude). If we represent the light of the faintest star visible to the naked eye by 0, and that of Aldebaran by 50, then Mira has fluctuated, in its maximum, between 20 and 47. Its probable brightness would be expressed by 30, and it is oftener below than above this limit: when it exceeds it, however, the excess is much greater in amount than is the defect when it falls below it. No decided period in these oscillations has yet been discovered, but there are indications of a period of 40, and of one of 160 years.

The periods of variation differ in different stars as much 1 : 250. The period of $\beta$ Persei of 68 hours 49 minutes is unquestionably the shortest, supposing that of Polaris, of less than 2 days, not to be confirmed. Next to $\beta$ Persei follow successively $\delta$ Cephei (5d. 8h. 49m.), $\eta$ Aquilæ (7d. 4h. 14m.), and $\zeta$ Geminorum (10d. 3h. 35m.) The variable stars of which the period has the longest duration are: 30 Hydræ Hevelii, 495 days; $\chi$ Cygni, 406 days; Variabilis Aquarii, 388 days; Serpentis S. 367 days; and Mira Ceti, 332 days. In several variable stars it is certain that the light increases more rapidly than it decreases: this phenomenon shews itself in the most striking manner in $\delta$ Cephei. Other stars have equal times of increasing and decreasing light (*ex. gr.* $\beta$ Lyræ). A difference in this respect is sometimes found in the same star. As a general

rule, Mira Ceti (like $\delta$ Cephei) increases faster than it decreases; but the contrary has also been observed.

In regard to periods which are themselves subject to a periodical variation, we find such decidedly in Algol, Mira Ceti, and $\beta$ Lyræ, and with much probability in $\chi$ Cygni. The decrease of the period of Algol is now undoubted. Goodricke did not find it, but Argelander has done so, having in 1842 been able to compare above 100 well-assured observations, of which the extremes are above 58 years apart, comprising 7600 periods. (Schumacher's Astr. Nachr. No 472 and 624.) The decrease of duration becomes more and more sensible. ([277]) For the periods of maximum in Mira (taking in the maximum of brightness observed by Fabricius in 1596), Argelander has given a formula ([278]) by which all the maxima can be so deduced that *the probable error* in a mean period of 331d. 8h. does not exceed 7 days, whereas on the assumption of a uniform period it would be 15 days.

The double maximum and minimum of $\beta$ Lyræ, in each of its periods of almost 13 days, were already very correctly recognised in 1784 by the discoverer Goodricke, but have been placed still more beyond doubt by the most recent observations. ([279]) It is worthy of notice, that this star attains the same degree of brightness in both its maxima, but at its principal minimum it is half a magnitude less than at its secondary minimum. From the earliest discovery of the variability of $\beta$ Lyræ its period was probably lengthening, but more and more slowly, until, between 1840 and 1844, the period ceased to increase, and has since decreased. We find something similar to the double maximum of $\beta$ Lyræ in $\delta$ Cephei; it has so far an inclination to a second maximum that the decrease of light does not proceed uniformly, but,

after having been at first rapid, comes after some time to a stand, or at least to a very inconsiderable degree of diminution; after which the decrease suddenly resumes a most rapid rate. It is as if the attainment of a second maximum was interfered with.

The question of whether there is, on the whole, more regularity in variable stars of very long than in those of very short periods, is one difficult to answer. The deviations from a uniform period can only be taken relatively, *i. e.* in parts of the period itself. In order to begin with long periods, $\chi$ Cygni, Mira Ceti, and 30 Hydræ, must be first considered. In $\chi$ Cygni, the deviations from the most probable period, on the assumption of a uniform variability (406·0634 days), is as great as 39·4 days. Even though a part of this may be ascribed to errors of observation, yet there will still certainly remain from 29 to 30 days, or $\frac{1}{14}$th of the whole period. In Mira Ceti, (280) in a period of 331·340 days, the deviations extend to 55·5 days, even if we leave out of the account the observations of David Fabricius. If, on account of errors of observation, we reduce the estimation to 40 days, we obtain a quotient of $\frac{1}{8}$th, or, as compared with $\chi$ Cygni, a deviation almost twice as great. In 30 Hydræ, which has a period of 495 days, the deviation is certainly still greater, perhaps amounting to $\frac{1}{5}$th. It is only within a few years, since 1840 and still later, that the variable stars with very short periods have been observed perseveringly and with due precision; so that, in regard to them, the question we are speaking of is still more difficult of solution. As far, however, as experience hitherto can enlighten us, the deviations would appear to be less considerable. In $\eta$ Aquilæ (Period 7d. 4h.) they are only $\frac{1}{16}$ or $\frac{1}{17}$th of the whole period; in $\beta$ Lyræ (Period 12d. 21h.) only $\frac{1}{27}$ or $\frac{1}{30}$th;

but as yet this investigation is still subject to many uncertainties in the comparison of long and short periods. Of $\beta$ Lyræ, from 1700 to 1800 periods have been observed; of Mira Ceti, 279; of $\chi$ Cygni, only 145.

The question which has been asked, whether stars which have long shewn themselves variable in regular periods cease to be so, would appear to require to be answered in the negative. If among the persistently varying stars there are some which shew sometimes a very great and sometimes a very slight degree of variability (for example, variabilis Scuti), there would also appear to be others whose variability is at certain times so small, that, with our limited means, we cannot detect it. The star variabilis Coronæ bor. (No. 5236 in the British Association Catalogue), of which Pigott recognised the variability, and which he observed for some time, belongs to this class. In the winter 1795-1796, this star was quite invisible: subsequently it reappeared, and its alterations of light were observed by Koch. Harding and Westphal, in 1817, found its brightness almost constant; but, in 1824, Olbers was again able to observe its change. Afterwards the constancy of light returned, and from August 1843 to September 1845 was observed by Argelander. At the end of the month of September, 1845, a fresh decrease began to take place. In October, the star was no longer visible in the Comet-seeker: it reappeared in February 1846, and in the beginning of June it had again attained its usual magnitude (the 6th), which it has since retained, if we omit the consideration of small and not very well assured fluctuations. To this perplexing class of stars the one called variabilis Aquarii also belongs, as does perhaps Janson's and Kepler's star in Cygnus, which appeared in 1600, and which we have already noticed among "New stars."

*Table of Variable Stars. By Fr. Argelander.*

| Number. | Name of the Star. | Duration of the Period. | | | Brightness at the Maximum. | Brightness at the Minimum. | Name of the Discoverer. | Date of Discovery. |
|---|---|---|---|---|---|---|---|---|
| | | days. | hours. | min. | Magnitude. | Magnitude. | | |
| 1 | $o$ Ceti | 331 | 20 | 0 | 4 to 2·1 | 0 | Holwarda | 1639 |
| 2 | $\beta$ Persei | 2 | 20 | 49 | 2·3 | 4 | Montanari | 1669 |
| 3 | $\chi$ Cygni | 406 | 1 | 30 | 6·7 to 4 | 0 | Gottfr. Kirch | 1687 |
| 4 | 30 Hydræ Hev. | 495 | 0 | 0 | 5 to 4 | 0 | Maraldi | 1704 |
| 5 | Leonis R., 420 M. | 312 | 18 | 0 | 5 | 0 | Koch | 1782 |
| 6 | $\eta$ Aquilæ | 7 | 4 | 14 | 3·4 | 5·4 | E. Pigott | 1784 |
| 7 | $\beta$ Lyræ | 12 | 21 | 45 | 3·4 | 4·5 | Goodricke | 1784 |
| 8 | $\delta$ Cephei | 5 | 8 | 49 | 4·3 | 5·4 | Goodricke | 1784 |
| 9 | $\alpha$ Herculis | 66 | 8 | 0 | 3 | 3·4 | William Herschel | 1795 |
| 10 | Coronæ R. | 323 | 0 | 0 | 6 | 0 | E. Pigott | 1795 |
| 11 | Scuti R. | 71 | 17 | 0 | 6·5 to 5·4 | 9 to 6 | E. Pigott | 1795 |
| 12 | Virginis R. | 145 | 21 | 0 | 7 to 6·7 | 0 | Harding | 1809 |
| 13 | Aquarii R. | 388 | 13 | 0 | 9 to 6·7 | 0 | Harding | 1810 |
| 14 | Serpentis R. | 359 | 0 | 0 | 6·7 | 0 | Harding | 1826 |
| 15 | Serpentis S. | 367 | 5 | 0 | 8 to 7·8 | 0 | Harding | 1828 |
| 16 | Cancri R. | 380 | 0 | 0 | 7 | 0 | Schwerd | 1829 |
| 17 | $\alpha$ Cassiopeiæ | 79 | 3 | 0 | 2 | 3·2 | Birt | 1831 |
| 18 | $\alpha$ Orionis | 196 | 0 | 0 | 1 | 1·2 | John Herschel | 1836 |
| 19 | $\alpha$ Hydræ | 55 | 0 | 0 | 2 | 2·3 | John Herschel | 1837 |
| 20 | $\epsilon$ Aurigæ | | ? | | 3·4 | 4·5 | Heis | 1846 |
| 21 | $\zeta$ Geminorum | 10 | 3 | 35 | 4·3 | 5·4 | Schmidt | 1847 |
| 22 | $\beta$ Pegasi | 40 | 23 | 0 | 2 | 2·3 | Schmidt | 1848 |
| 23 | Pegasi R. | 350 | 0 | 0 | 8 | 0 | Hind | 1848 |
| 24 | Cancri S. | | ? | | 7·8 | 0 | Hind | 1848 |

*Remarks: by Fr. Argelander.*

Zero, in the column of minimum, denotes that the star is then fainter than the 10th magnitude. For the sake of indicating, in a convenient and simple manner, the smaller variable stars, which for the most part have neither names nor other designations, I have permitted myself to attach letters to them; and as the greater part of the Greek and small Latin alphabets have been already employed by Bayer, I have taken capital letters.

Besides the stars given in the table, there is an almost equal number which are surmised to be variable because different observers have assigned to them different magnitudes. But as such estimations were only occasional, and not made with great precision, and as different observers follow different principles in the estimation of magnitudes, it seems safer not to include such stars until a decided variation in them at different times shall have been found by the same observer. This is the case with all the stars given in the above table, and the fact of their change of light is well assured, even where no determination of its period has yet been possible. The periods assigned rest, for the most part, on my own investigations and examinations, both of older published observations, and of those made by myself and still unprinted which extend over more than ten years. The exceptions will be stated in the following notices.

In these notices the positions are for 1850, and are expressed in Right Ascension and Declination. The often-employed expression, *gradation,* signifies such a difference of brightness as can be securely recognised, either with the

naked eye, or, in stars not visible to the naked eye, with a Fraunhofer's Comet-seeker of 24 Parisian inches focal length. For the brighter stars above the 6th magnitude, a gradation is about the 10th part of the difference between two successive orders of magnitude; for the smaller stars, the magnitudes in ordinary use are considerably closer together.

1. *o* Ceti, R. A. 32° 57′, Decl. −3° 40′; also called Mira, on account of its wonderful change of light, the phenomenon having been first observed in this star. The periodicity of the change was already recognised in the second half of the 17th century, and Bouillaud determined the duration of the period at 333 days; it was also found at the same time that this duration was sometimes longer and sometimes shorter, as well as that the light of the star, when at the greatest, was sometimes brighter and sometimes fainter. This has since been perfectly confirmed. Whether the star ever becomes quite invisible has not yet been decided; it has sometimes been seen of the 11th or 12th magnitude at the time of the minimum, and at other times it has not been possible to see it with 3 and 4 feet telescopes. Thus much is certain, that it is for a long time fainter than the 10th magnitude. There are, however, few existing observations of it at this stage; most observations commencing only when, being of the 6th magnitude, it begins to shew itself to the naked eye. From that moment the star increases in brightness, at first rapidly, then more slowly, and afterwards more rapidly. On the mean, the time occupied by the increase of light, from the 6th magnitude upwards, is 50 days, and by the decrease of light, down to the same degree of brightness,

69 days; so that the star is visible to the naked eye for an interval of about four months. This is, however, only the mean duration of the star's visibility, which has sometimes been augmented to five, and sometimes diminished to only three months. So, also, the relative duration of the increase and decrease of light is subject to great fluctuations, the former being sometimes slower than the latter: as was the case in 1840, when the star took 62 days to arrive at its greatest brightness, and in 49 days decreased from thence to invisibility to the naked eye. The shortest observed duration of the increase was 30 days, in 1679; the longest, 67 days, in 1709. The decrease lasted longest in 1839, when it extended over 91 days, and was shortest in 1660, when it was only 52 days. Sometimes, at the time of its greatest brightness, the light of the star scarcely undergoes any sensible change in the course of an entire month; at other times an alteration is distinctly perceptible at the end of a few days. Sometimes, after the star has decreased in brightness for some weeks, a suspension of change for several days ensues, or at least the decrease becomes scarcely sensible: this was the case in the years 1678 and 1847.

As already noticed, the maximum brightness is by no means always the same. If we represent the light of the faintest star visible to the naked eye by 0, and that of Aldebaran, a star of the first magnitude, by 50, then the observed maximum brightness of Mira has fluctuated between 20 and 47, *i. e.* between the brightness of stars of the 4th and of the 1st to the 2nd magnitudes: the mean brightness is 28, or that of the star $\gamma$ Ceti. The duration of the period has been almost even more irregular:

in the mean it is 331 days 20 hours, but its fluctuations are as great as a month; for the shortest time which has been known to elapse from one maximum to the next was only 306, and the longest was 367 days. These irregularities become still more striking if we compare the epochs of the actually observed maxima of light with the results which would be obtained by calculating them upon the assumption of a uniform period. The differences between calculation and observation amount to 50 days; and these differences are found to be nearly the same and on the same side for several successive years. This circumstance clearly indicates that the luminous phenomena are affected by a perturbation of long period. More exact calculation has proved, however, that one perturbation does not suffice, and that we must assume several, which may indeed proceed from the same cause, one returning after 11, a second after 88, a third after 176, and a fourth after 264 single periods. According to these assumptions we may derive a formula of sines [278] with which the several maxima now shew a very near accordance, although there still remain deviations which cannot be explained by errors of observation.

2. β Persei, Algol; R. A. 44° 36′; Decl. + 40° 22′. Although Geminiano Montanari first remarked the variability of this star in 1667, and although it was also observed by Maraldi, yet it was Goodricke who, in 1782, first made out the regularity of the variations. The reason of this may very probably be, that this star does not increase and decrease gradually, as do most of the other variable stars, but for 2 days and 13 hours shines constantly with the same brightness (2·3 m.), and only

shews a less degree of light for between 7 and 8 hours, in the course of which it descends to the 4th magnitude. The decrease and increase of brightness are not quite regular, but, proceeding more rapidly near the minimum, enable the moment of least brightness to be determined to within 10 or 15 minutes. It is remarkable that, after increasing in light for the space of an hour, it remains for about the same time at almost exactly the same degree of brightness, after which it again begins to increase sensibly. Hitherto the length of the period has been supposed to be perfectly uniform, and Wurm was able to represent all the observations well, by taking it at 2d. 21h. 48m. 58·5s. A more exact calculation, with an interval almost twice as great as that which Wurm had at his command, has, however, shewn that the period is becoming gradually shorter. In 1784 it was 2d. 20h. 48m. 59·4s., and in 1842 only 2d. 20h. 48m. 55·2s. The latest observations render it very probable, also, that this decrease of the period is taking place more rapidly than before, so that, for this star also, there will in time be derived a formula of sines for the perturbation of the period. The present shortening of the period might be explained by the assumption, that Algol either approaches us nearer every year by about 2000 geographical miles, or recedes from us that quantity less each year than the preceding; as in such case the light would reach us each year as much sooner as the diminution of the period requires, *i. e.* about 12 thousandth parts of a second. Should this be the true reason, there would naturally be deduced in time, a formula of sines.

3. $\chi$ Cygni, R. A. 269° 12′; Decl. + 32° 32′. This

star also shews nearly the same irregularities as Mira: the deviations of the observed maxima from the results calculated on the supposition of a uniform period are as much as 40 days, but are very greatly diminished by the introduction of a perturbation of 8½ single periods, and another of 100 such periods. At its maximum of brightness, this star reaches, on the mean, a faint 5m., or one gradation brighter than the star 17 Cygni. But here also the fluctuations are very considerable, and have been observed from 13 gradations below the mean to 10 above it. If the star never exceeded the weaker maximum, it would be altogether invisible to the naked eye, whereas, in 1847, it could be seen for fully 97 days without a telescope; the mean duration of its visibility is 52 days, of which 20 days in the mean are occupied by the increase, and 32 by the decrease.

4. 30 Hydræ Hevelii, R. A. 200° 23′; Decl. 22° 30′. Of this star, which from its position in the heavens can only be seen for a short time in each year, all that can yet be said is, that both its period and its maximum brightness are subject to great irregularities.

5. Leonis R=420 Mayeri; R. A. 144° 52′, Decl. + 12° 7′. This star has often been confounded with the neighbouring stars 18 and 19 Leonis, and has on that account been very little observed; it has, however, been sufficiently so, to shew that the period is rather irregular. The maximum brightness also appears to fluctuate through some gradations.

6. $\eta$ Aquilæ, also called $\eta$ Antinoi; R. A. 296° 12′; Decl + 0° 37′. The period of this star is tolerably uniform, 7d. 4h. 53m. 53s.; but yet the observations

shew, that in longer intervals of time small fluctuations occur; not, however, exceeding about 20 seconds. The change of light even proceeds with so much regularity, that hitherto no deviations have been perceptible which may not be explained by errors of observation. At its minimum this star is a gradation fainter than $\iota$ Aquilæ; it then increases, at first slowly, then more rapidly, and then more slowly; and 2d. 9h. after the minimum it attains its greatest brightness, when it is almost three gradations brighter than $\beta$, but still 2 gradations fainter than $\delta$ Aquilæ. The decrease from the maximum is less regular, for when the star has declined to the brightness of $\beta$, which it reaches 1 day and 10 hours after the maximum, it alters more slowly than before or afterwards.

7. $\beta$ Lyræ, R. A. 281° 8′, Decl. + 33° 11′; a remarkable star, in having two maxima and two minima. At its lowest minimum it is $\frac{1}{3}$rd of a gradation fainter than $\zeta$ Lyræ; it then rises in 3d. 5h. to its first maximum, in which it continues to be $\frac{3}{4}$ths of a gradation fainter than $\gamma$ Lyræ. It then sinks in 3d. 3h. to its secondary minimum, in which its brightness exceeds that of $\zeta$ by 5 gradations. After 3d. 2h. more, it reaches its second maximum, when it has again the same brightness as in the first, and then sinks again in 3d. 12h. to its lowest minimum; so that it passes through its whole variation of light in 12d. 21h. 46m. 40s. This duration, however, only holds good for the years 1840 to 1844: before that time the period was less; in 1784 by $2\frac{1}{2}$ hours, in 1817 and 1818 by more than an hour, and now there is evidently again a shortening of the period. No doubt, therefore, it will be possible, in the case of this star also,

to express the perturbation of the period by a formula of sines.

8. $\delta$ Cephei, R. A. 335° 54′, Decl. + 57° 39′. Is of all known stars the one which shews the greatest regularity in all respects. The period of 5d. 8h. 47m. 39·5s. represents all observations from 1784 to the present time, to within the limits of errors of observation, which errors may also suffice for the explanation of the small differences which shew themselves in the march of the variations of light. At its minimum the star is $\frac{3}{4}$th of a gradation brighter than $\epsilon$ Cephei, and at its maximum it is equal to $\iota$ of the same constellation; it takes 1d. 15h. to rise from the minimum to the maximum, and more than double that time, *i.e.* 3d. 18h. to return to the minimum; after which, however, it scarcely alters at all for eight hours, and only quite inconsiderably for an entire day.

9. $\alpha$ Herculis, R. A. 256° 57′, Decl. + 14° 34′. A very red double star, whose variation of light is irregular in every respect. Often it scarcely alters at all for months, at other times it is five gradations brighter at its maximum than at its minimum, and hence the period is also still very uncertain. The discoverer assumed it at 63 days; I began by taking it at 95, until a careful calculation of all my observations during seven years gave me the period assigned in the text. Heis thinks that he can represent the observations by a period of 184d. 9h., having two maxima and two minima.

10. Coronæ R., R. A. 235° 36′, Decl. + 28° 37′. This star is only occasionally variable; the assigned period was calculated by Koch from his own observations, which are unfortunately lost.

11. Scuti R., A. R. 279° 52′, Decl.—5° 51′. Sometimes the fluctuations of the light of this star are comprised within a few gradations, whilst at other times it sinks from the 5th to the 9th magnitude. It has been still too little observed to permit us to decide whether any determinate rule prevails in these alterations. The length of the period is also subject to considerable fluctuations.

12. Virginis R., R. A. 187° 43′, Decl. + 7° 49′. Its period and maximum brightness are tolerably regular, yet deviations occur which appear to me too large to be ascribed solely to errors of observation.

13. Aquarii R, R. A. 354° 11′, Decl. − 16° 6′.

14. Serpentis R, R. A. 235° 57′, Decl. + 15° 36′.

15. Serpentis S, R. A. 228° 40′, Decl. + 14° 52′.

16. Cancri R, R. A. 122° 6′, Decl. + 12° 9′.

Respecting these four stars, observations of which are exceedingly scanty, there is little more to be said than is given in the table.

17. *α* Cassiopeiæ, R. A. 8° 0′, Decl. + 55° 43′. This star is very difficult to observe; the difference between maximum and minimum only amounts to a few gradations, and is moreover as variable as is the length of the period. The very different results assigned for it are attributable to this circumstance. The result which I have given represents sufficiently well the observations from 1782 to 1849, and appears to me the most probable.

18. *α* Orionis, R. A. 86° 46′, Decl. + 7° 22′. The variation in the light of this star from the minimum to the maximum only amounts to four gradations; it increases in brightness during 91½ days, and decreases during 104½: its decrease from the 20th to the 70th day after the maxi-

mum is quite insensible. Sometimes its variation of light is still less, and scarcely noticeable. It is very red.

19. $\alpha$ Hydræ, R. A. 140° 3′, Decl. − 8° 1′. Is of all variable stars the most difficult to observe, and the period is still quite unassured. Sir John Herschel gives it at 29 or 30 days.

20. $\epsilon$ Aurigæ, R. A. 72° 48′, Decl. + 43° 36′. Either the changes of light in this star are very irregular, or in a period of several years there are several maxima and minima: this can only be determined after a lapse of many years.

21. $\zeta$ Geminorum, A. R. 103° 48′, Decl. + 20° 47′. Hitherto this star has shewn an entirely regular course in its changes of light. At the minimum its brightness is half way between $\nu$ and $\upsilon$ of the same constellation, and at the maximum not quite equal to $\lambda$; it occupies 4d. 21h. in increasing, and 5d. 6h. in decreasing.

22. $\beta$ Pegasi, R. A. 344° 7′, Decl. + 27° 16′. The period is already pretty well determined, but there is as yet nothing to be said about the regularity or otherwise of the variation of its light.

23. Pegasi R, R. A. 344° 47′, Decl. + 9° 43′.

24. Cancri S, R. A. 128° 50′, Decl. + 19° 34′.

There is as yet nothing to be said respecting these two stars.

Fr. Argelander.

Bonn, August 1850.

In the scientific investigation of important natural phenomena, whether in the telluric or in the sidereal sphere of the Cosmos, prudence commands us not to be too hasty in

linking together phenomena whose immediate causes are still veiled in obscurity. For this reason we willingly distinguish between newly appeared stars which have again entirely disappeared (as the star in Cassiopeia in 1572); newly appeared stars which have not disappeared again (as the star in Cygnus, 1600); variable stars whose periods have been investigated (as Mira Ceti, Algol, &c.); and stars whose luminous intensity varies without our having as yet discovered any periodicity in the variation, (as $\eta$ Argûs). It is not at all improbable, but it also by no means necessarily follows, that these four kinds of phenomena (281) arise from similar causes belonging to the photospheres of those distant suns, or to the nature of their surfaces.

As we began the description of the new stars with the most remarkable instance of this class of celestial events, *i. e.* the sudden appearance of the star of Tycho Brahe,—so, guided by the same reasons, we will begin the description of the alteration of the light of stars, in which the periodicity of the variation has not yet been investigated, by the still proceeding unperiodic fluctuations of luminous intensity in the star $\eta$ Argûs. This star is situated in the great and magnificent constellation of the Ship, which is the "glory of the southern heavens." As early as 1677, Halley, on his return from his voyage to St. Helena, expressed many doubts respecting change of light in the stars of the Ship Argo, particularly on the shield of the prow and on the deck (*ἀσπιδισκη* and *κατάστρωμα*), whose relative order of magnitude had been given by Ptolemy (282); but from the uncertainty of the star positions of the Ancients, the many variations in the manuscripts of the Almagest, and the uncertain estimations of luminous intensity, these doubts could not lead to any results.

In 1677 Halley had found $\eta$ Argûs of the 4th magnitude; in 1751 Lacaille found it already of the 2d. Afterwards the star returned to its earlier fainter intensity, for Burchell, during his residence in Southern Africa in 1811—1815 found it of the 4th magnitude. From 1822 to 1826 Fallows and Brisbane saw it of the 2nd magnitude; and in February 1827, Burchell, who was then at St. Paul in Brazil, found it of the 1st magnitude, and quite equal to $\alpha$ Crucis. After a year it returned to the 2nd magnitude; it was found so by Burchell in the Brazilian town of Goyaz on the 29th February, 1828, and was so entered by Johnson and Taylor in their registers from 1829 to 1833. Sir John Herschel at the Cape of Good Hope also estimated it from 1834 to 1837 at between the 2nd and 1st magnitude.

But on the 16th of December, 1837, when the last named celebrated astronomer was preparing to make photometric measurements of the numberless telescopic stars of the 11th to the 16th magnitudes which fill the fine nebula around $\eta$ Argûs, he was astonished at finding this often observed star increased to such an intensity of light, that it almost equalled the brightness of $\alpha$ Centauri, and surpassed that of all other stars of the first magnitude except Canopus and Sirius. It had attained the maximum of its brightness on that occasion on the 2nd of January, 1838. It soon became fainter than Arcturus, but still surpassed Aldebaran in the middle of April 1838. It went on decreasing until March 1843, always continuing, however, to be a star of the 1st magnitude, but we then find, particularly in April of the same year, that the light began to increase again to such a degree, that according to the observations of Mackay at Calcutta, and of Maclear at the Cape, $\eta$ Argûs became brighter than Canopus,

and even almost equal to Sirius. ([283]) It has retained this degree of brightness very nearly to the commencement of the present year. A distinguished observer, Lieutenant Gilliss, who has the command of the Astronomical Expedition which the Government of the United States has sent to the coast of Chili, writes from Santiago in February 1850 : "$\eta$ Argûs with its yellowish red light, which is darker than that of Mars, now comes next to Canopus in brightness, and is brighter than the united light of $\alpha$ Centauri." ([284]) Since the appearance of the new star in Ophiuchus in 1604, no fixed star has brightened to such an intensity of light, and for a continuance of now already seven years. In the 173 years (from 1677 to 1850) during which we have accounts of the magnitude of this fine star, it has undergone eight or nine oscillations of increase and decrease. It was a fortunate circumstance, and one which has stimulated the persevering attention of astronomers to the phenomenon of a great but unperiodic variability in this star, that it should have manifested itself in the most striking manner during the memorable five years' expedition of Sir John Herschel to the Cape of Good Hope.

Similar variations of light which have not yet been recognised as periodical have been remarked in several other instances, both in isolated fixed stars and in double stars observed by Struve (Stellarum compos. Mensuræ microm. p. lxxi.—lxxiii.) The examples which it may suffice to cite here are founded on actual photometric estimations and measurements made at different times by the same astronomers, and not at all upon the alphabetical series in Bayer's Uranometry. Argelander, in the treatise "de fide Uranometriæ Bayerianæ," 1842, in p. 15, has shown very

convincingly that Bayer did not follow the principle of always indicating the brightest stars by the first letters; but that, on the contrary, in the *same* star-magnitude he distributed the letters in the order of *position* in such manner as to pass usually from the head of the figure, in each constellation, to its feet. The alphabetical order of the letters employed in Bayer's Uranometry has long given prevalence to a belief in changes having taken place in the light of $\alpha$ Aquilæ, of Castor, and of Alphard.

Struve (1838) and Sir John Herschel saw Capella increase in light. Sir John Herschel now estimates Capella as much brighter than Vega, whereas he formerly always considered it fainter (285). Galle and Heis form the same judgment from a present comparison of Capella and Vega: Heis considers the latter star to be between five and six gradations, or more than half a magnitude, fainter than Capella.

The alterations in the light of some stars in the constellations of the Great and Little Bear, are deserving of particular attention. "The star $\eta$ Ursæ majoris," says Sir John Herschel, "is now certainly the brightest of the seven bright stars in the Great Bear, whilst in 1837 the first rank belonged incontestably to $\varepsilon$." This remark occasioned me to make inquiries from Heis, who occupies himself with so much ardour, and so extensively, with the variability of the light of stars. He wrote to me in reply to the following effect:—"From the mean of the observations made by me at Aix-la-Chapelle from 1842 to 1850, I find the order of succession thus: 1. $\varepsilon$ Ursæ maj., or Alioth; 2. $\alpha$ or Dubhe; 3. $\eta$ or Benetnasch; 4. $\zeta$ or Mizar; 5. $\beta$; 6. $\gamma$; 7. $\delta$. In respect to the differences of brightness between these seven stars, $\varepsilon$,

$\alpha$ and $\eta$ are nearly equal to each other; so that, when the atmosphere is not quite clear, their order of succession may appear doubtful: $\zeta$ is decidedly fainter than $\varepsilon$, $\alpha$, and $\eta$. The two stars $\beta$ and $\gamma$, both sensibly fainter than $\zeta$, are almost equal to each other. Lastly, $\delta$, which in old maps is given as equal with $\beta$ and $\gamma$, is more than an entire order of magnitude fainter than those stars. $\varepsilon$ is certainly variable: although usually brighter than $\alpha$, I have five times in three years seen it decidedly fainter than $\alpha$. I also regard $\beta$ Ursæ majoris as variable, but without being able to assign any determinate period. Sir John Herschel, in 1840 and 1841, found $\beta$ Ursæ min. much brighter than Polaris; whereas, in May 1846, the contrary was observed by him. He surmises variability in $\beta$ (286). Since 1843, I have usually found Polaris fainter than $\beta$ Ursæ min.; but between October 1843 and July 1849 my registers show that, on fourteen occasions, Polaris was seen to exceed $\beta$ in brightness. I have repeatedly had an opportunity of convincing myself that the last-named star is not always equally reddish: it is sometimes more or less yellow, and sometimes very decidedly red" (287). All laborious investigations of the relative brightness of stars will gain essentially in certainty, when successive arrangement according to mere estimation shall be finally superseded by methods of measurement founded on the progress of modern optical science (288), and astronomers and physicists ought not to doubt the possibility of attaining such an object.

From the probably great physical similarity of the luminous process in all self-luminous celestial bodies (in the central body of our own planetary system, and in the remoter suns or fixed stars), it has long been justly pointed out, (289) how important a bearing the periodical or non-periodical variation

of light in stars may possibly have on climatology in general, —on the history of the terrestrial atmosphere, *i. e.* on the varying quantity of heat received in the course of ages by our planet from solar radiation,—and on the condition of organic life, and its forms of development, in different latitudes. The variable star, Mira Ceti, changes from the 2d to the 11th magnitude, and even to entire disappearance; and we have just seen that $\eta$ Argûs has increased from the 4th to the 1st magnitude, and even to the brightness of Canopus, and almost to that of Sirius. If only a very small part of such alterations of luminous intensity and radiant heat, either in the ascending or descending scale, should have taken place in our Sun (and why should it be different from other suns?), they would have produced more powerful and even more fearful consequences to our planet, than are required for the explanation of all geological relations and ancient telluric revolutions. William Herschel and Laplace were the first who called attention to these considerations. If I thus notice them in this place, however, it is not because I would seek exclusively in them for the solution of the great problem of the alterations of temperature upon our globe. It may also have been that the primitive high temperature of the planet due to the manner of its formation and to its consolidation,—the radiation of heat through deep fissures or open clefts, and veins not yet filled with metallic ores,—more powerful electric currents,—and a very different distribution of land and sea,—*may*, in the earlier ages of our planet, have rendered the distribution of temperature independent of latitude, *i. e.* of position relatively to the Sun. Cosmical contemplation ought not to limit itself by too partial a view to astrognostic relations only.

## V.

PROPER MOTION OF THE FIXED STARS.—PROBLEMATICAL EXISTENCE OF DARK BODIES.—PARALLAX.—MEASURED DISTANCE OF SOME FIXED STARS.—DOUBTS CONCERNING THE ASSUMPTION OF A CENTRAL BODY FOR THE WHOLE SIDEREAL HEAVENS.

BESIDES variations of luminous intensity, the heaven of the *fixed* Stars, in contradiction to its name, also undergoes variation from the perpetually progressive motion of the several stars. It has already been recalled how, without the general equilibrium of the sidereal system being disturbed thereby, no point in the entire heavens has remained fixed,—how, of the bright stars observed by the most ancient of the Greek astronomers, none has maintained its position in space unaltered. In two thousand years, the change of place, by the accumulated effects of annual proper motion, has amounted in Arcturus, $\mu$ Cassiopeiæ, and a double star in Cygnus to spaces corresponding to $2\frac{1}{2}$, $3\frac{1}{2}$, and 6 diameters of the moon. At the end of three thousand years, about 20 fixed stars will have altered their place 1° and upwards. (290) As the proper motions of fixed stars which have been measured vary from $\frac{1}{20}$th or ·05 of a second to 7·7 seconds, (differing, therefore, at least in the

proportion of 1 : 154), it follows that the relative distances of the fixed stars, *inter se*, and the configuration of the constellations does not remain the same for long periods. The Southern Cross will not always shine in the heavens in the same form which that constellation now presents, as the four stars of which it is composed move with unequal velocities in different paths. How many thousand years may be required for the entire dissolution of the constellation is not to be calculated. In relations of space and time, there is no absolute great or small. If we would embrace in a general view the changes which take place in the heavens, modifying in the course of ages the "physionomic character" of the celestial canopy, or the aspect of the firmament as seen at a determinate point of the earth's surface, we must enumerate, as efficient causes of such alteration, (1) the precession of the equinoxes and the nutation of the earth's axis, by the joint influence of which new stars arise above the horizon, and others become invisible; (2) the periodic and non-periodic variations of luminous intensity in many fixed stars; (3) the shining forth of new stars, some few of which have remained; (4) the revolution of telescopic double stars round a common centre of gravity. Amongst these so-called fixed stars, which vary slowly and unequally in intensity of light and in position, 20 planets, and 20 satellites belonging to five of these planets, complete their more rapid course. Thus, besides the countless hosts of (also, without doubt, revolving) fixed stars, there are discovered up to the present time (October 1850), 40 planetary bodies. In the time of Copernicus, and of the great improver of the art of observation, Tycho Brahe, only 7 were known. We might also have named here as planetary bodies almost

200 calculated comets, of which 5 are of short periods of revolution, and interior, *i. e.* their paths are entirely comprised between those of the principal planets. During their mostly short appearance, they, or rather those amongst them which are visible to the naked eye, as well as the true planets, and those bodies which have suddenly shone forth as new stars of the first magnitude, animate, in the most attractive manner, the already rich picture of the sidereal heavens.

The knowledge of the proper motion of the fixed stars is wholly connected, historically, with the advances which have been made in the art of observing by the improvement of instruments and of methods. It first became possible to discover these motions when telescopes were combined with graduated instruments,—when astronomers were able progressively to advance from certainty in respect to a minute of arc (which Tycho Brahe first succeeded, by the most strenuous endeavours, in giving to his observations in the Island of Huen), to certainty in respect to seconds and parts of seconds,—and when it was possible to compare together results separated by a long series of years. Such a comparison was made by Halley, who employed in it the positions of Sirius, Arcturus, and Aldebaran, as entered by Ptolemy in his Hipparchian Catalogue, 1847 years before. He thought himself justified by this comparison (1717) in announcing the existence of a proper motion in the three above named fixed stars. (291) The great and deserved regard which, even long after Flamsteed's and Bradley's observations, was paid to the Right Ascensions contained in Römer's Triduum, incited Tobias Mayer (1756), Maskelyne (1770), and Piazzi (1800), to compare Römer's observations with later ones. (292)

These comparisons led, as early as the middle of the last century, to the recognition of the proper motion of the fixed stars generally; but we are indebted for more exact and numerical determinations of this class of phenomena, first to the great work of William Herschel in 1783, founded on Flamsteed's observations ([293]), and since in a far higher degree to Bessel's and Argelander's comparison of Bradley's Star Positions for 1755 with later catalogues.

The discovery of the proper motion of the fixed stars, is of so much the higher importance to physical astronomy, since it has led to the recognition of the movement of our own solar system through star-filled space, and even to the exact knowledge of the direction of this movement. This is a fact of which we could never have become aware, if the progressive proper motion of the fixed stars had been so small as altogether to escape our measurement. The zealous endeavour to investigate the quantity and direction of this movement, together with the parallax of the fixed stars and their distance, by stimulating the improvement of arc-graduation and micrometric apparatus combined with optical instruments, has eminently contributed to the advance of observing astronomy to the point to which, (especially since 1830), it has been raised by the judicious employment of large meridian-circles, refractors, and heliometers.

The quantity of proper motion which has been measured in different stars varies, as I have remarked in the beginning of this section, from the 20th part of a second to almost 8 seconds. The brighter stars have in many cases a less motion than stars of the 5th, 6th, and 7th magnitudes. ([294]) The 7 stars which have shewn unusually great proper

motion, are, Arcturus (1st magnitude) which has an annual proper motion of 2″·25; α Centauri (1st m.), 3″·58 ([295]); μ Cassiopeiæ (6th m.), 3″·74; the double star δ in Eridanus (5·4 m.) 4″·08; the double star 61 Cygni (5·6 m.), 5″·123, the motion being recognised by Bessel in 1812 by compa-rison with Bradley's observations; a star on the borders of the constellations Canis Venaticus ([296]) and Ursus Major, No. 1830 of Groombridge's catalogue of circumpolar stars (7th m.), according to Argelander 6″·974; ε Indi, 7″·74 according to D'Arrest ([297]); 2151 Puppis (6th m.) 7″·871. The arithmetical mean ([298]) of the several proper motions of fixed stars, taken from all the zones into which Mädler has divided the celestial sphere, would hardly exceed 0″·102.

An important investigation into the variability of the proper motions of Procyon and Sirius, had in 1844 (a short time before the commencement of his painful and fatal illness), impressed the mind of the greatest astronomer of our time, Bessel, with the conviction, "that stars, whose variable motions become sensible when examined with the most perfect instruments, are parts of systems which are limited to spaces small in comparison with the great distances of the fixed stars from each other." This belief in the existence of double stars, of which one member of the pair is supposed to be non-luminous, was so strong in Bessel's mind (as his long correspondence with myself testified), as to add greatly to the general interest excited by whatever promises to enlarge our knowledge of the physical constitution of the sidereal heavens. "The attracting body," said he, "must be situated either very near the star which shews the observed change of place,

or very near the sun. But since nothing in the motions of our planetary system betrays the presence of an attracting body of considerable mass at a very small distance from the sun, we are conducted back to the supposition of the existence of such a body at a *very small distance from a star*, as the only valid explanation of an alteration in the proper motion of the latter becoming visible in the course of a century." (299) In a letter to myself, in July 1844, (I had sportively expressed some uneasiness at the idea of such a ghost-world of dark stars), he said, "I do, indeed, continue in the belief, that Procyon and Sirius are both true double stars, each consisting of one visible and one invisible star. There is no *à priori* reason for regarding luminosity as an essential property of bodies. The countless host of visible stars clearly proves nothing against the possible existence of an equally countless host of invisible stars. The physical difficulty of a variation in the proper motion, is satisfactorily met by the hypothesis of dark stars. The simple supposition cannot be blamed, that an alteration of velocity only takes place in obedience to a force, and that forces act according to the Newtonian laws."

A year after Bessel's death, Fuss, at Struve's instance, renewed the investigation of the anomalies of Procyon and Sirius, partly by new observations with Ertel's Meridian Telescope at Pulkova, and partly by reductions and comparison with earlier observations. Struve and Fuss (300) consider the result to be against Bessel's opinion. On the other hand, a laborious inquiry, just completed by Peters at Königsberg, and a similar one by Schubert, the calculator employed on the North American Nautical Almanac, support Bessel.

The belief in the existence of non-luminous stars was already prevalent in Grecian antiquity, and especially in the early times of Christianity. It was assumed that "among the fiery stars which are nourished by vapours, there move other earthy bodies which remain invisible to us." (301) The entire extinction of new stars, particularly of those in Cassiopeia and Ophiuchus, so carefully observed by Tycho Brahe and Kepler, appeared to afford a firmer support to this notion. As it was then supposed that the first-named of these two stars had already shone forth twice before, at intervals of about 300 years, the idea of annihilation or complete dissolution was not likely to find acceptance. The illustrious author of the "Mécanique Céleste" founds his persuasion of the existence of non-luminous masses in the Universe on the same phenomena of 1572 and 1604. "Ces astres devenus invisibles après avoir surpassé l'éclat de Jupiter même, n'ont point changé de place durant leur apparition." (Only the luminous process in them has ceased.) "Il existe donc dans l'espace celeste des corps opaques aussi considerables et peut-être en aussi grands nombres que les étoiles". (302) So also Mädler, in his "Untersuchungen über die Fixstern-Systeme" (303) says, "A dark body might be a central body; it might, like our sun, be only surrounded in its immediate vicinity by dark bodies such as are our planets. The movements of Procyon and Sirius pointed out by Bessel constrain (?) the assumption that there are cases in which luminous bodies are satellites to dark masses." I have already noticed that some adherents of the emanation-theory of light supposed such masses to be light-radiating, though at the same time invisible from being of such enormous dimensions that the

rays of light sent forth (luminous molecules) are so held back by the force of attraction, that they cannot pass beyond a certain limit. ([304]) If, as may well be assumed, there are dark invisible bodies in space in which the process of light-producing undulations does not take place, they must either not fall within the circumference of our planetary and cometary system, or they must be of very small mass, since their presence does not manifest itself by any perceptible perturbations.

The investigation of the motion of the fixed stars in amount and direction (meaning thereby both their true proper motion, and the merely apparent motion due to the change in the observer's place caused by the earth's motion in her orbit),—the determination of the distance of the fixed stars from the Sun by investigations of their parallax,—and conjectures as to the part of space towards which our planetary system is moving;—are three problems in Astronomy which, in respect to the means of observation which have been successfully employed in their partial solution, are nearly allied to each other. Every improvement, either of instruments or of methods, applied to the advancement of one of these difficult and complicated inquiries, has been productive of benefit to the others. I prefer commencing with the parallaxes, and with the determination of the distances of some of the fixed stars, in order to complete the account of the present state of our knowledge in reference to single fixed stars.

As early as the beginning of the 17th century, Galileo put forward the idea of "measuring the, doubtless very unequal, distances of the fixed stars from the solar system"; and even

with great acuteness, proposed the means of finding the parallax, not by the determination of the distance of a star from the zenith or the pole, but "by the careful comparison of one star with another very near to it." Although expressed in very general terms, this is the micrometric method subsequently employed by William Herschel (1781), Struve and Bessel. "Perchè io non credo," said Galileo (305) in his third discourse (Giornata terza), "che tutte le stelle siano sparse in una sferica superficie *egualmente distanti da un centro;* ma stimo, che le loro lontananze da noi siano talmente varie, che alcune ve ne possano esser 2 e 3 volte più remote di alcune altre; talchè quando si trovasse col Telescopio *qualche picciolissima stella vicinissima ad alcuna delle maggiori,* e che però quella fusse altissima, *potrebbe accadere, che qualche sensibile mutazione succedesse tra di loro.*" The promulgation of the Copernican system carried with it the grounds for requiring the numerical assignment by measurement of the change of direction, which the half-yearly change of place of the Earth, in her orbit round the Sun, must produce in the apparent position of the fixed stars. But as the angular determinations of Tycho Brahe, so happily employed by Kepler, (although, as I have already said, they might be considered certain to one minute of arc), still did not shew any such change arising from parallax, the Copernicans long satisfied themselves by replying to such requirements, that the diameter of the Earth's orbit, (41⅓ German, 165⅓ English millions of geographical miles), was too small in proportion to the exceedingly great distance of the fixed stars.

The hope of being able to discover by observation the existence of parallax, must therefore have been seen to be de-

pendent on the improvement of optical and measuring instruments, and on the possibility of determining very small angles with certainty. So long as such certainty was only equal to one minute, the non-detection of parallax only proved that the fixed stars must be more distant than 3438 semi-diameters of the Earth's orbit. ([306]) Certainty to a second in the observations of the great Astronomer, James Bradley, raised this lower limit to 206265 semi-diameters; and in the brilliant epoch of the Fraunhofer instruments, it was raised, by the direct measurement of nearly the tenth part of a second of arc, to 2062648 semi-diameters of the Earth's orbit. The efforts, and ingeniously devised Zenith apparatus, of Newton's great cotemporary, Robert Hooke, in 1669, did not conduct to the desired aim. Picard, Horrebow who worked out Römer's rescued observations, and Flamsteed thought they had found parallaxes of several seconds, because they confounded the proper motions of the Stars with the effects of parallax. On the other hand, the sagacious John Michell (Phil. Trans. 1767, Vol. lvii. pp. 234-264), was of opinion that the parallaxes of the nearest fixed stars must be less than $0''\cdot02$, and therefore "could only be recognised by a magnifying power of 12000." From the very prevalent idea that the superior brightness of a star must always indicate its greater proximity, stars of the first magnitude, Vega, Aldebaran, Sirius, and Procyon, were first studied, and were the subjects of the unsuccessful observations of Calandrelli, and of the meritorious Piazzi. (1805) To these observations, we must add those which were published (1815) in Dublin by Brinkley, and which, ten years later, were refuted by Pond, and especially by Airy. A sure and satisfactory knowledge of parallaxes, founded on micrometric

measurements, only commenced between the years 1832 and 1838.

Although Peters, [307] in his important work on the distances of fixed stars (1846), gives the number of cases of parallax already discovered at 33, I will content myself with citing nine, which deserve, though in very unequal degrees, the greatest amount of confidence, giving them nearly in the order of time of their determinations.

The first place belongs to the Star 61 Cygni, which Bessel has rendered so celebrated. As early as 1812, the Königsberg astronomer determined the large proper motion of this double star (below the sixth magnitude); but it was only in 1838, that he ascertained its parallax by the employment of the heliometer. My friends Arago and Mathieu made a series of numerous observations, from August 1812 to November 1813, for ascertaining the parallax of 61 Cygni by measuring its Zenith distance. They arrived at the very just conjecture, that the parallax of the Star must be less than half a second.[308] As late as 1815 and 1816, Bessel, as he himself expresses it, "had not arrived at any admissible result." [309] Observations from August 1837 to October 1838, in which he availed himself of the large heliometer established in 1829, first led him to infer a parallax of $0''\cdot3483$, corresponding to a distance of 592200 semi-diameters of the Earth's orbit, and to a passage of light of $9\frac{1}{4}$ years. Peters, in 1842, confirmed this result, by finding $0''\cdot3490$; subsequently, however, Bessel's result was converted by a temperature correction into $0''\cdot3744$. [310]

The parallax of the finest double Star in the Southern Heavens, *a* Centauri, has been determined by observations at the Cape of Good Hope, by Henderson in 1832, and by

Maclear in 1839, at 0″·9128. ([311]) This would make it the nearest of all the fixed Stars whose parallaxes have yet been measured, and three times nearer than 61 Cygni.

The parallax of *α* Lyræ, has long been the subject of Struve's observations. The earlier observations (1836) gave ([312]) between 0″·07 and 0″·18; later ones gave 0″·2613, and a distance of 771400 semi-diameters of the Earth's orbit, with a light passage of 12 years; ([313]) but Peters has found the distance of this bright Star still greater, since he gives its parallax at only 0″·103. This result contrasts with another Star of the first magnitude (*α* Centauri), and with a Star of the sixth magnitude (61 Cygni).

The parallax of Polaris was determined by Peters, by many comparisons made in the years 1818—1838, at 0″·106, and the more satisfactorily as the same comparisons give the aberration 20″·455. ([314])

The parallax of Arcturus is, according to Peters, 0″·127 (Rumker's earlier observations with the Hamburgh Meridian Circle had given it much larger). The parallax of another star of the 1st magnitude, Capella, is still less, being, according to Peters, 0″·046.

The Star 1830 of Groombridge's Catalogue, which, according to Argelander, has shown the greatest proper motion of any star yet observed, has a parallax of 0″·226, as inferred from 48 very exactly observed Zenith distances by Peters in 1842 and 1843. Faye had believed it to be 5 times greater, viz., 1″·08, or more considerable than the parallax of *α* Centauri. ([315])

The following table contains the parallaxes of the nine stars which deserve the greatest amount of confidence, with the names of the observers, and the probable errors of the determinations.

| Fixed Stars. | Parallaxes. | Probable Errors. | Names of Observers. |
|---|---|---|---|
| α Centauri ........... | 0″·913 | 0″.070 | Henderson & Maclear. |
| 61 Cygni.............. | 0″.3744 | 0″·020 | Bessel. |
| Sirius ................. | 0″·230 | ...... | Henderson. |
| 1830 Groombridge .. | 0″ 226 | 0″·141 | Peters. |
| ι Ursæ maj............ | 0″·133 | 0″·106 | Peters. |
| Arcturus .............. | 0″·127 | 0″·073 | Peters. |
| α Lyræ .............. | 0″·207 | 0″·038 | Peters. |
| Polaris .............. | 0″·106 | 0″·012 | Peters. |
| Capella .............. | 0″ 046 | 0″·200 | Peters. |

The results hitherto obtained by no means show generally that the brightest stars are also the nearest. Although the parallax of *α* Centauri is indeed the largest hitherto known, yet, on the other hand, *α* Lyræ, Arcturus, and especially Capella, have parallaxes from 3 to 8 times less than a star of the 6th magnitude in Cygnus. It is also to be remarked that the two stars which, next to 2151 Puppis and ε Indi, show the most rapid proper motion, *i. e.*, the Star in Cygnus which has just been named (having an annual motion of 5″·123), and No. 1830 of Groombridge, called in France Argelander's Star (annual

motion $6''\cdot974$), are, the one 3, and the other 4 times as far from the Sun as $\alpha$ Centauri, which has a proper motion of $3''\cdot58$. Volume, mass, intensity of light, proper motion ([316]), and distance from our solar system, are certainly in very various and complicated relations to each other. Although, therefore, it may be generally probable that the brightest stars are the nearest, yet there may be individual cases of very remote small stars whose photospheres and surfaces may, from the nature of their physical constitution, support a very intense luminous process. Stars, which on account of their brightness we reckon as belonging to the 1st magnitude, may thus be really more distant from us than stars which we call of the 4th, 5th, or 6th magnitudes. If we descend from the consideration of the great sidereal stratum, of which our solar system is a part, to the subordinate particular system of our planetary world, and step by step, still lower, to the systems of Jupiter and Saturn with their respective satellites, we see central bodies surrounded by masses in which the succession of magnitudes and of intensities of reflected light does not appear to depend at all on distance. The immediate connection subsisting between our direct knowledge, still so slight, of the parallaxes of stars, and our knowledge of the entire structural form of the universe, gives a peculiar interest and charm to considerations which relate to the distance of the fixed stars.

Human ingenuity has devised for this class of investigations a method quite different from those usually employed; it is founded on the velocity of light, and deserves to be briefly noticed in this place. Savary, of whom the physical sciences have been too early deprived, has shown how, in

double stars, the aberration of light may be used for determining the parallax. If the plane of the orbit, which the secondary star describes round the central body, is not perpendicular to the line of sight from the earth to the double star, but, on the contrary, nearly coincides with it, then the course of the secondary star will appear to be in a right line, and the points on the half of its orbit which is turned towards the earth will all be nearer the observer, than the corresponding points of the other half which is turned from the earth. Such a division into two halves produces, not a really, but to the observer an apparently, unequal velocity according as the smaller star is approaching or receding from him. If, then, the semi-diameter of the orbit is so large that light requires several days or weeks to traverse it, then the time of the semi-revolution on the farther side will be greater than on the side turned towards the observer. The sum of the two unequal numbers which express the duration of the two semi-revolutions, is still equal to the true period of entire revolution, since the inequalities occasioned by the cause referred to mutually destroy each other. In Savary's ingenious method, by converting days and parts of days into a standard of length (light traverses 14356 millions of geographical miles in 24 hours), it is possible to deduce from these ratios of duration the absolute magnitude of the semi-diameter of the orbit, and by the simple determination of the angle under which the semi-diameter presents itself to the observer, the *distance* of the central body and its parallax. [317]

As the determination of the parallaxes informs us concerning the distances of a small number of fixed stars and

the position in space to be assigned to them, so the knowledge of the measure and direction of their proper motion (*i. e.* of the changes experienced by the relative positions of self-luminous bodies) conducts us to two problems dependent on each other; viz., the motion of our solar system, ([318]) and the situation of the centre of gravity of the whole heaven of the fixed stars. What can as yet only be reduced in so very incomplete a manner to numerical relations, must for that very reason be ill adapted for the clear manifestation of casual connection. Of the two last named problems, the first only has received a solution, in particular by Argelander's excellent investigation, which can be viewed as in some degree of a satisfactory definiteness; the second, in which so many opposing and mutually compensating forces are concerned, has been treated with great ingenuity by Mädler; but, according to that astronomer's own avowal, ([319]) the attempted solution is deficient in "all the evidences of a complete and scientifically adequate demonstration."

After carefully separating and deducting all that belongs to the precession of the equinoxes, the nutation of the earth's axis, the aberration of light, and the parallactic change occasioned by the earth's revolution round the Sun, the remaining annual motion of the fixed stars still includes both the effects of the *movement of translation of the entire solar system in space*, and those of the true proper motion of the fixed stars themselves. In Bradley's admirable investigation of nutation in his great work in 1748, we find the first expressed anticipation of the translation of the solar system, and also an indication of the method of observation most desirable to be pursued for its discovery. "If," says he, ([320]) "it should be found that our planetary

system changes its situation in absolute space, there may thence arise, in course of time, an apparent variation in the angular distance of the fixed stars. Now, as in such case the position of the stars nearest to us would be more affected than that of the more distant ones, the position of these two classes of stars would appear altered relatively to each other, although in themselves they might all have remained unmoved. If, on the other hand, our solar system is in repose, and some stars actually move, then their apparent positions will also be altered; and this the more as the motions are more rapid, the stars in a favourable position, and the distance from the earth less. The alteration in their relative positions may be dependent on so great a number of causes that, perhaps, many centuries may be required before the laws can be discovered."

After Bradley, sometimes the mere possibility, and sometimes the greater or less probability of the movement in space of the solar system, were discussed in the writings of Tobias Mayer, Lambert, and Lalande; but William Herschel had first the merit of supporting the opinion by actual observation (1783, 1805, and 1806). He found, what many later and more exact investigations have confirmed and determined within narrower limits of uncertainty, that our solar system is moving towards a point near the constellation of Hercules in R.A. 260° 44′, and North Declination 26° 16′ (reduced to 1800). Argelander, by a comparison of 319 Stars, and taking into account Lundahl's investigations, found for the situation of this point, for 1800; R.A. 257° 54′·1; Decl. + 28° 49′·2; and for 1850; R.A. 258° 23′·5; Decl. + 28° 45′·6; and Otto Struve (from 392 Stars) found it for 1800, R.A. 261° 26′·9, Decl. + 37°

35′·5, and for 1850, R.A. 261° 52′·6 and Dec. 37° 33′·0. According to Gauss, ([321]) the place sought for is situated within a quadrangle whose angular points are in

| | | | |
|---|---|---|---|
| R.A. | 258° 40′ | and Decl. | +30° 40′ |
| „ | 258° 42′ | „ | 30° 57′ |
| „ | 259° 13′ | „ | 31° 9′ |
| „ | 260° 4′ | „ | 30° 32′ |

It still remained to examine what result would be obtained by employing stars of the Southern Hemisphere, which never rise above the horizon in Europe. Galloway has devoted himself with great diligence to this research. He has compared very recent determinations (1830) by Johnson at St. Helena, and by Henderson at the Cape of Good Hope, with determinations of older date, (1750 and 1757) of Bradley and Lacaille. The result ([322]) has been, for 1790, R.A. 260° 0′, Decl. + 34° 23′, and therefore for 1800 R.A. 260° 5′, Decl. + 34° 22′; and for 1850, 260° 33′ and + 34° 20′. This agreement with the results obtained from Northern Stars is extremely satisfactory.

If, then, we may consider the direction of the progressive movement of our solar system to be determined within moderate limits, the questions very naturally arise,—Is the world of the fixed stars distributed into groups, each consisting only of neighbouring partial systems?—or must we imagine a general relation, *i.e.* that all self-luminous celestial bodies (suns) revolve around a common *centre of gravity, either occupied by a mass of matter, or void, i.e.* not so occupied? We are here entering on the domain of mere conjecture, to which a scientific form may indeed be given, but which, from the insufficiency of the data at our com-

mand, either as the results of observation or of analogy, are not capable of leading to such evidence as other parts of Astronomy enjoy.

One reason which especially opposes a thorough mathematical treatment of problems so difficult of solution, consists in our ignorance of the proper motion of a countless host of very small stars (10th to 14th magnitude), which appear scattered amongst brighter ones, and most abundantly in what is so important a part of our sidereal stratum, the rings of the Milky Way. The consideration of our planetary sphere, in which we ascend from the small partial systems of Jupiter, Saturn, and Uranus with their respective satellites, to the general solar system, easily led to the belief that the fixed stars might be imagined to be in an analogous manner divided into many single groups, which, though separated by wide intervals, might yet (in the higher relation of such groups to each other) be all subjected to the preponderating attracting force of a great central body, which might be regarded, as it were, as the one central *Sun* of the Universe. ([323]) But the series of consequences here alluded to as having been based on the analogy of our solar system, is opposed by the facts of observation as known to us up to the present time. In the "Multiple Stars," two or more self-luminous heavenly bodies or suns do not revolve around each other, but around a centre of gravity situated far outside of them. It is true that in our planetary system, something similar takes place, inasmuch as the planets revolve, not around the centre of the body of the solar orb itself, but around the centre of gravity of all the masses of the system. This common centre of gravity falls, according to the relative position of the larger planets, Jupiter

and Saturn, sometimes within the corporeal circumference of the Sun, and sometimes (and this is the more frequent case) on the outside of that circumference. ([324]) Thus the centre of gravity, which in the double stars is void, is in the solar system sometimes void, and sometimes occupied by matter. All that has been said respecting the possibility of the assumption of a dark central body in the centre of gravity of the double stars, or of planets originally dark but faintly illuminated by foreign light revolving around them, belongs to the wide domain of mythical hypothesis.

It is a graver consideration, and one more deserving of a thorough examination, that, if we assume a movement of revolution, both for our own entire solar system, and for all the proper motions of the fixed stars situated at such widely different distances from us, the *centrum* of this revolving motion must be 90° from the point ([325]) towards which our solar system is moving. In reference to the combination of ideas which is here introduced, the situation of the stars, which have, on the one hand, a very considerable, or, on the other hand, a very slight proper motion, becomes of great moment. Argelander has cautiously, and with his own peculiar sagacity, tested the degree of probability with which, in our own sidereal stratum, a general centrum of attraction might be sought for in the sidereal constellation of Perseus. ([326]) Mädler, rejecting the hypothesis of a central body occupying the place of the general centre of gravity, and being itself of preponderating mass, seeks the centre of gravity in the group of the Pleiades, and in the middle of the group, in or near ([327]) the bright star $\eta$ Tauri (Alcyone). This work is not the place for examining the degree of probability, on the one

hand, or, on the other, the insufficiency of the foundation, [328] of this last supposition. With the distinguished and active director of the Observatory at Dorpat, rests the merit of having in his laborious investigation examined the position and proper motion of upwards of 800 fixed stars, and of having at the same time given activity to researches, which, if they do not conduct to a satisfactory resolution of the great problem itself, are yet suited to throw light on kindred subjects in physical astronomy.

# VI.

## MULTIPLE, OR DOUBLE STARS.—THEIR NUMBER AND DISTANCES APART.—PERIOD OF REVOLUTION OF TWO SUNS ROUND A COMMON CENTRE OF GRAVITY.

If, in considerations on the subject of the fixed stars, we descend from conjectural, higher and more general relations, to such as are more special, we find ourselves on ground firmer and better adapted for direct observation. In *multiple stars*, to which class *binary* or *double stars* belong, several self-luminous cosmical bodies (Suns) are connected with each other by mutual attraction, and this attraction necessarily calls forth motion in re-entering curved lines. Previous to the recognition, by actual observation, of the revolutions of double stars, (329) our knowledge of the existence of motion in re-entering curved lines was limited entirely to our own planetary solar system. On this apparent analogy hasty inferences were based, which led aside from the true path. As the name of double-star was applied in all cases where proximity prevented separation by the unassisted eye (as in Castor, $\alpha$ Lyrae, $\beta$ Orionis, and $\alpha$ Centauri), the term very naturally came to include two classes of multiple stars; those whose proximity might be occasioned solely by their accidental position in relation to the observer, while they

might really be situated at very different distances, and might belong to altogether different sidereal strata,—and those which, being actually and truly near to each other, and being connected by mutual dependence or reciprocal attraction, form a particular system of their own. It is now the custom to call the first class *optically*, and the second *physically*, double stars. Very great distance and slowness of elliptic motion, may possibly cause several of the latter class to be confounded with the former. To cite here a well-known object, the small star Alcor, (which received much attention from Arabian astronomers, because visible to the naked eye in very clear atmosphere and to persons whose visual organs are very perfect,) forms, *in the widest sense of the term*, such an optical combination as has been spoken of, with ζ in the tail of the Great Bear. I have already noticed in Sections II. and III. the difficulty of separating with the unassisted eye adjacent stars of very unequal intensity of light,—the influence generally of such inequality of light,—the rays which appear to issue from stars,—and the organic defects which produce indistinctness of vision. ([330])

Galileo, without making double stars a particular subject of his telescope observations, (for which, indeed, the magnifying powers employed by him would have been quite inadequate), yet in a celebrated passage of the Giornata terza of his Discourses, pointed out by Arago, mentions the use which astronomers might make of optically double stars (quando si trovasse nel telescopio qualche picciolissima stella, vicinissima ad alcuna delle maggiori), for discovering parallax in the fixed stars. ([331]) Until the middle of the last century, star-catalogues scarcely contained notices of as many as 20

double stars, exclusive of such as are more than 32″ apart; now, a hundred years later (thanks principally to the great labours of the two Herschels and Struve), there have been discovered in both hemispheres about 6000. Among the earliest described double stars, (332) are ζ Ursæ maj. (7th Sept. 1700, by Gottfried Kirch), α Centauri (1709, by Feuillée), γ Virginis (1718), α Geminorum (1719), 61 Cygni (1753, the distances and angles of direction were observed in this and the two preceding cases by Bradley), p Ophiuchi, and ζ Cancri. The number of double stars enumerated gradually augmented, from Flamsteed who employed a micrometer, to the Star Catalogue of Tobias Mayer, which appeared in 1756. Two men, sagacious in conjecture and apt in combination of thought, Lambert ("Photometria," 1760; and "Cosmological Letters on the Arrangement of the Structure of the Universe," 1761), and John Michell (1767), although they did not themselves observe double stars, were the first who promulgated just views respecting the relations of attraction of stars in partial binary systems. Lambert, like Kepler, ventured to suppose the distant suns (fixed stars), to be, like our own sun, surrounded by dark bodies, as planets and comets, but respecting fixed stars in near proximity to each other, (although he otherwise seems inclined to entertain the supposition also of dark central bodies), his belief was, (333) that they performed within a moderate time a revolution around their common centre of gravity. Michell, (334) who had no knowledge of Kant's and Lambert's ideas, was the first who, with much sagacity, applied the calculus of probabilities to close groups of stars, especially to multiple stars, binary and quaternary. He showed the probabilities to be 500,000 to 1 against the

juxtaposition of the six principal stars in the Pleiades being accidental, and thence inferred that their grouping must rather be supposed to be founded on some peculiar relation existing between them. He felt so certain of the existence of luminous stars which move round each other, that he proposed to apply these partial star-systems to the ingenious solution of some astronomical problems. ([335])

The Manheim astronomer, Christian Mayer, has the great merit of having first (1778) made the double stars a special object of research by the sure path of actual observation. The name which he unfortunately selected of "fixed-star satellites," and the relations which he thought he recognised between stars $2\frac{1}{2}°$ and $2° 55'$ distant from Arcturus, exposed him to the bitter attacks of his cotemporaries, and among the number to the censure of the great and acute mathematician, Nicolaus Fuss. That dark bodies should become visible by reflected light at such enormous distances was indeed improbable. The results of observations carefully planned and executed were unfortunately disregarded, because the proposed systematic explanation of the phenomena was rejected; and yet, in a paper written in his own defence against Maximilian Hell, Director of the Imperial Astronomical Observatory at Vienna, Mayer had expressly said, "that the small stars which are so near large ones may be either planets dark in themselves, but illuminated by reflected light, *or*, that both bodies, *i. e.*, the principal star and its companion, may *both* be self-luminous suns revolving round each other." Long after Mayer's death, that which is important in his works has been gratefully and publicly acknowledged by Struve and Mädler. In his two Memoirs, entitled, "Vertheidigung neuer Beobachtungen von Fix-

stern-trabanten (1778), and Diss. de novis in Cœlo sidereo Phænomenis (1779)," 80 multiple stars observed by him are described, among which 67 are less than 32″ apart. The greater number were new discoveries of his own made with the excellent eight-feet telescope of the Manheim Mural quadrant; "some are still amongst the most difficult objects, and which can only be shown by powerful instruments; as ρ and 71 Herculis, ε Lyræ, and ω Piscium." Mayer, indeed (as, however, was still done long after his time), only measured distances in Right Ascension and Declination by his meridian instrument; and from his own observations, and those of earlier astronomers, showed changes of position, from the numerical values of which he erroneously did not deduct what (in particular cases) belonged to the proper motions of the stars ([336]).

These slight but memorable beginnings were followed by William Herschel's colossal work on multiple stars. It embraces a period of more than 25 years; for although the first table of Herschel's double stars was published 4 years after Mayer's Memoir on the same subject, yet Herschel's observations go back to 1779, or even, if we include his investigations on the trapezium in the great nebula in Orion, to 1776. Almost all that we now know relative to the several classes of double stars has its origin in Sir William Herschel's work. He not only gave in the catalogues of 1782, 1783, and 1804, the positions and angular distances apart of 846 double stars ([337]), the majority of which were discovered exclusively by himself; but what is much more important than the increase of number, he exercised his acute sagacity and true spirit of observation on all that relates to the paths, supposed periods of revolution, luminous intensity, contrast

of colours, and classification according to the degree of distance apart, of the double stars. Imaginative, and yet always advancing with caution, he expressed himself, in the year 1794, when distinguishing between optically and physically double stars, in a brief and preliminary manner respecting the nature of the relation subsisting between the larger star and its smaller companion. Nine years afterwards, he first developed the entire connection and mutual dependence of the phenomena, in the 93rd volume of the Philosophical Transactions. The idea of partial star-systems, in which two or more suns revolve around a common centre of gravity, was now firmly established. The powerful dominion of attracting forces, which, in our solar system, extends to Neptune, at a mean solar distance 30 times greater than that of the Earth (or 2488 millions of geographical miles), and even constrained the great comet of 1680 to return when at a distance equal to 28 distances of Neptune, or 70,800 millions of geographical miles,—also, reveals itself in the motion of the double star 61 Cygni, which, in correspondence with a parallax of 0″·3744, is 18,240 distances of Neptune, or 550,900 semi-diameters of the Earth's orbit, or 11,394,000 German or 45,576,000 English millions of geographical miles from our sun. If, however, the causes and the general connection of the phenomena were very distinctly recognised by William Herschel, yet in the first ten years of the 19th century, the angles of position derived from his own observations, and from older star-catalogues employed without sufficient care, belonged to epochs too close together, to admit of the periods of revolution or the elements of the orbits being derived with due certainty from the several numerical values. Sir

John Herschel himself notices the very uncertain assignments of the periods of $\alpha$ Geminorum (334 years instead of, according to Mädler, 520), ([338]); of $\gamma$ Virginius (708 years instead of 169); and of $\gamma$ Leonis (1424 of Struve's great catalogue), a superb pair of stars, golden yellow and reddish-green (1200 years).

After William Herschel, the foundations of this important branch of astronomy were laid in a more thorough and special manner by Struve (Senior), 1813—1842, and Sir John Herschel, 1819—1838, with admirable activity and by the aid of highly improved instruments (more particularly in micrometric apparatus). Struve published his first Dorpat Table of double stars (796 in number) in 1820. This was followed in 1824 by a second, containing 3112 double stars down to the 9th magnitude at distances apart less than 32″, only about one-sixth of which had been previously seen. For the execution of this work, 120000 fixed stars had been examined in the great Fraunhofer refractor. Struve's third Table was published in 1837, and forms the important work entitled, "Stellarum Compositarum Mensuræ micrometricæ." ([339]) It contains, (several insecurely observed objects being carefully excluded,) 2787 multiple stars.

During Sir John Herschel's four years' residence at Feldhausen, at the Cape of Good Hope, a residence which constitutes an epoch in respect to the more exact topographical knowledge of the southern heavens, his perseverance enriched the department of astronomy which we are now considering by upwards of 2100 double stars, which, with a few exceptions, had never been observed before. ([340]) All these African observations were made with a twenty-feet

reflector; they are reduced to 1830, and are arranged in 6 Catalogues, which contain 3346 double stars, and were presented by Sir John Herschel to the Royal Astronomical Society of London, for the 6th and 9th parts of their valuable memoirs. ([341]) In the European portion of these catalogues, there are included 380 double stars which were observed in 1825 by the above-named celebrated astronomer, conjointly with Sir James South.

We see by this historical account, how, in the course of half a century, science has gradually arrived at an extensive and accurate knowledge of partial, and more particularly of binary, star systems existing in space. The number of double stars (including those both optically and physically double) may now be estimated with some degree of security at 6000, including those observed by Bessel with the fine Fraunhofer heliometer, by Argelander ([342]) at Abo (1827—1835), by Encke and Galle at Berlin (1836 and 1839), by Preuss and Otto Struve at Pulkova (since the Catalogue of 1837), by Mädler at Dorpat, and by Mitchell at Cincinnati in Ohio with a 17 feet Munich Refractor. In how many of these cases the stars seen in close proximity in the telescope are really connected with each other by immediate relations of attraction, forming particular systems and revolving in closed orbits,—*i. e.* how many are what are called physically double stars,—is an important question, but one difficult to answer. More and more revolving companions are gradually being discovered. Extraordinary slowness of motion, or the circumstance of the direction of the plane of the orbit, as it presents itself to our eyes, being such that the position of the moving star is unfavourable for observation, may long cause *physically*

double stars to be included by us among *optically* double stars in which the proximity is only apparent. But a distinctly recognised measurable motion, such as we have been speaking of, is not the only criterion; Argelander and Bessel have shown, in a considerable number of multiple stars, a perfectly equal proper motion in space (*i. e.* a *common* progressive movement, such as that of our own solar system, including, together with the Sun, all its planets and satellites), which testifies in favour of the principal stars and their companions being respectively connected with each other by a true and actual relation, forming separate partial systems. Mädler has made the interesting remark that,—whereas in 1836, among 2640 catalogued double stars, there were only 58 in which a difference of relative position had been observed with certainty, and 105 in which such a difference could be regarded as indicated with a greater or less degree of probability,—the proportion of physical to optical double stars is now so changed in favour of the first, that among 6000 multiple stars there are, according to a Table published in 1849, six hundred and fifty ([343]) in which an alteration of relative position can be demonstrated. The earlier ratio gave 1 in 16, the latter one already gives 1 in 9, for the proportion of cases in which the motions of the principal star and its companion show these celestial bodies to be physically double.

The relative distribution of binary star-systems, not only in the celestial spaces generally, but even simply on the apparent heavenly vault, has as yet been but little examined numerically. In the Northern Hemisphere, double stars are most frequent in the *direction* of certain constellations (Andromeda, Boötes, the Great Bear, the Lynx, and Orion).

In the Southern Hemisphere, we have from Sir John Herschel, the unexpected result that, "in the extra-tropical parts, the number of multiple stars is *much less* than in the corresponding parts of the Northern Hemisphere." And yet these fair southern regions were examined with an excellent 20-feet reflector, which separated stars of the 8th magnitude in distances of only three-fourths of a second apart, under the most favourable atmospheric conditions, and by a most practised observer. ([344])

An exceedingly remarkable peculiarity of multiple stars, consists in the occurrence among them of contrasted colours. Struve, in his great work published in 1837, gave the following results in respect to colours, derived from 600 of the brightest double stars. ([345]) In 375 cases, the colour of the principal star and the companion was the same, and equally intense. In 101, the colour was the same, but a difference of intensity was perceived. The cases of double or multiple stars having entirely different colours, were 120 in number, or one-fifth of the whole; whereas uniformity of colour between the principal stars and their companions, extended to four-fifths of the entire carefully examined mass. In almost half the 600 cases, both the principal star and the companion are white. Among those in which the colours are different, combinations of yellow and blue (as in $\iota$ Cancri), and of reddish-yellow and green (as in the ternary star $\gamma$ Andromedæ), ([346]) are very frequent.

It was Arago who in 1825 first called attention to the circumstance, that in most, or at least in very many cases, the diversity of colour in binary systems appeared to have reference to *complementary* colours (*i. e.* to the subjective relation between colours, the union of which forms white). ([347])

It is a well-known optical phenomenon, that a faint white light appears green, when a strong (intense) red light is brought near to it; and that white light becomes blue, when the surrounding stronger light is yellowish. Arago, however, cautiously and justly remarked, that, although the green or the blue colour of the companion may sometimes be the result of contrast with the brighter star, yet that the actual existence of green or of blue stars is by no means to be denied. ([348]) He gives instances in which a bright white star (1527 Leonis, 1768 Can. ven.) is accompanied by a small blue star; cites a double star (δ Serp.), in which both the principal star and its companion are blue; ([349]) and proposes a mode of examining whether the contrasted colour is merely subjective, by covering the principal star in the telescope, when the distance permits, by a wire, or by a diaphragm. Usually it is the smallest star only which is blue; it is otherwise, however, in the double star 23 Orionis (696 of Struve's catalogue, p. lxxx), in which the principal star is bluish, and the companion pure white. If, in the multiple stars, the different coloured suns are often surrounded by planets invisible to us, such planets must be variously illuminated, having their white and blue, or their red and green days. ([350])

As we have already seen ([351]) in a preceding section, that the periodical variability is not necessarily associated with a red or reddish colour, so also neither is colour in general, nor a contrasted diversity of colour in the principal star and its companion in particular, a characteristic of double stars. Circumstances, which we find to be frequent, are not therefore general and necessary conditions of the phenomena, whether of the periodical variation of the light of stars, or

of the revolution of sidereal bodies in partial systems round a common centre of gravity. A careful examination of the brighter double stars (colour is still determinable in stars of the 9th magnitude), teaches us that, besides pure white, all the colours of the solar spectrum are to be found in double stars; but that the principal star, when not white, generally approximates to the red extreme, namely, that of the least refrangible rays, and the companion to the violet extreme, or that of the most refrangible rays. The reddish stars are twice as frequent as the blue and bluish, and the white are about twice and a half as numerous as the red and reddish. It is also to be remarked, that usually a great difference of colour is combined with a considerable difference in the intensity of the light. In two pairs of stars, which, from their great brightness, can be easily measured in the daytime with powerful telescopes,—$\zeta$ Boötis and $\gamma$ Leonis,—the first-named pair consists of two white stars of the 3rd and 4th magnitudes, and the latter of a principal star of the 2m., and a companion of the 3·5m. This last-named star ($\gamma$ Leonis) is said to be the finest double star of the Northern Hemisphere, but $\alpha$ Centauri ([352]) and $\alpha$ Crucis, of the Southern Heavens, surpass all other double stars in brilliancy. As in $\zeta$ Boötis, so also in $\alpha$ Centauri and $\gamma$ Virginis, we remark the rare combination of two large stars having but little inequality of light.

Respecting variability of brightness in multiple stars, and especially respecting variability in the companion, unanimity and certainty do not yet prevail. We have already spoken more than once ([353]) of the somewhat irregular variability of the brightness of the principal star of a yellowish-red colour, in $\alpha$ Herculis. Also the variation of brightness, observed by

Struve (1831-1833), in the nearly equally bright yellowish stars (3rd magnitude) of the double star $\gamma$ Virginis and Anon. 2718, may perhaps indicate a very slow rotation around the axes of those two suns. ([354]) Whether any actual change of colour has ever taken place in double stars ($\gamma$ Leonis and $\gamma$ Delphini?), whether white light ever becomes coloured in them,—as we know that inversely in Sirius, which is a single star, coloured light has become white,—is still undecided; ([355]) when the differences in question only have reference to faint shades of colour, organic individuality in the observers, and when refractors are not employed, the often reddening influence of the metallic speculum in telescopes, are to be taken into account.

Among the multiple stars, or systems, I may cite:—ternary; $\xi$ Libræ, $\zeta$ Cancri, 12 Lyncis, 11 Monoceritis:—quaternary; 102 and 2681 of Struve's catalogue, $\alpha$ Andromedæ and $\varepsilon$ Lyræ:—and a six-fold combination in $\theta$ Orionis, the celebrated trapezium in the great nebula in Orion, probably forming a single physical system united by laws of mutual attraction, since the five smaller stars (6·3m.; 7m.; 8m.; 11·3m.; and 12m.) follow the proper motion of the principal star (4·7m). As yet, however, no change in their relative positions has been observed. ([356]) In two ternary multiple stars, $\xi$ Libræ and $\zeta$ Cancri, the movement of revolution of both companions has been recognised with great certainty; $\zeta$ Cancri consists of three stars differing but little in brightness, being all of the 3rd magnitude, and the nearer companion appears to have a ten times quicker motion than the more distant one.

The number of double stars, in which it has been possible to compute the elements of the orbits, is given at present

as from 14 to 16. ([357]) Of these ζ Herculis, since its first discovery, has already twice completed its circuit of revolution; and in so doing has presented (in 1802 and 1831) the phenomenon of the apparent occultation of one fixed star by another. We are indebted for the earliest calculations of the orbits of double stars to the industry of Savary (in the case of ξ Ursæ majoris), Encke (70 Ophiuchi), and Sir John Herschel; and they have been since followed by Bessel, Struve, Mädler, Hind, Smyth, and Captain Jacob. Savary's and Encke's methods require four complete observations sufficiently distant from each other. The shortest periods of revolution yet known are of 30, 42, 58, and 77 years, intermediate, therefore, between those of the planets Saturn and Uranus; the longest periods yet determined with any degree of certainty exceed 500 years, or are about three times as long as that of Le Verrier's planet Neptune. According to the investigations hitherto made, the excentricity of the orbits of double stars appears to be extremely considerable, resembling that of comets; in the case of σ Coronæ it is 0·62, in that of α Centauri 0·95. The least excentric internal comet, that of Faye, has an excentricity of 0·55, or less than that of the orbits of the two double stars just named; excentricities much smaller are presented, according to Mädler's and Hind's calculations, by η Coronæ and Castor, being 0·29 in the former, and 0·22 or 0·24 in the latter. In these double stars, therefore, the suns describe ellipses, which approximate closely to those of two of the smaller planets of our solar system, as the orbit of Pallas has an excentricity of 0·24, and that of Juno 0·25.

If with Encke we regard the brighter of the two stars in a binary system as being in repose, and accordingly refer to

it the motions of its companion, we find, from the observations hitherto made, that the companion describes round the principal star a conic section in the focus of which the latter is placed; or an ellipse in which the radius vector of the revolving body passes over equal areas in equal times. Exact measurements of angles of position and of distances, adapted for determinations of orbits, have already shewn, in the case of a considerable number of double stars, that the companion moves round the principal star considered as a body at rest, in obedience to the same gravitating forces which prevail in our solar system. This well-established conviction, gained within scarcely a quarter of a century, marks one of the great epochs in the history of the development of the higher cosmical knowledge. Celestial bodies, to which the name of fixed stars (assigned by ancient usage) is still given, although they are neither affixed to the heavenly vault nor motionless, have been seen to occult each other. The knowledge of the existence of partial systems, the several parts of which have motions referable to and dependent on each other, extends our views the more widely as those motions are again subordinated to more general ones.

The table on the next page contains the Elements of the orbits of six double stars, the determinations of which appear entitled to principal confidence.

## ELEMENTS OF THE ORBITS OF DOUBLE STARS.

| NAME. | SEMI MAJOR AXIS. | ECCENTRICITY. | PERIOD OF REVOLUTION IN YEARS. | COMPUTER. |
|---|---|---|---|---|
| 1. ξ Ursæ Maj. ... | 3″·857 | 0·4164 | 58·262 | Savary, in 1830. |
| „ | 3″·278 | 0·3777 | 60·720 | John Herschel, Table of 1849. |
| „ | 2″·295 | 0·4037 | 61·300 | Mädler, 1847. |
| 2. p Ophiuchi ...... | 4″·328 | 0·4300 | 73·862 | Encke, 1832. |
| 3. ζ Herculis ...... | 1″·208 | 0·4320 | 30 22 | Mädler, 1847. |
| 4. Castor ............ | 8″·086 | 0·7582 | 252·66 | John Herschel, Table of 1849. |
| „ | 5″·692 | 0·2194 | 519 77 | Mädler, 1847. |
| „ | 6″·300 | 0·2405 | 632·27 | Hind, 1849. |
| 5. γ Virginis ...... | 3″·580 | 0·8795 | 182·12 | John Herschel, Table of 1849. |
| „ | 3″·863 | 0·8806 | 169·44 | Mädler, 1847. |
| 6. α Centauri ...... | 15″·500 | 0·9500 | 77·00 | Captain Jacob, 1848. |

## VII.

THE NEBULÆ.—WHETHER ALL NEBULÆ ARE MERELY REMOTE AND VERY DENSE CLUSTERS OF STARS? – THE TWO MAGELLANIC CLOUDS IN WHICH NEBULÆ AND NUMEROUS CLUSTERS OF STARS ARE CROWDED TOGETHER.—THE BLACK PATCHES OR "COAL-SACKS" OF THE SOUTHERN CELESTIAL HEMISPHERE.

Besides the visible celestial bodies which shine with sidereal light,—either by their own proper light, or by planetary illumination, either isolated, or variously associated forming multiple stars and revolving round a common centre of gravity,—we behold also other forms or masses having a milder, fainter, nebulous, lustre ([358]). These,—which are seen in some instances as small disk-shaped luminous clouds having a well-defined outline, whilst in other instances their forms vary greatly, their boundaries are ill-defined, and they are spread over much wider spaces in the sky,—appear at the first glance, to the assisted eye which views them through the telescope, to differ altogether from the heavenly bodies which have been treated of in detail in the four preceding sections. As astronomers have been inclined to infer from the observed but hitherto unexplained movements of visible stars ([359]) the existence of other *unseen* celestial bodies,

so the experience of the resolvability of a considerable number of nebulæ has led in the present and most recent times to inferences as to the non-existence of any true nebulæ, and even of any cosmical or celestial nebulosity whatsoever. Whether, however, the well-defined nebulæ of which I have spoken be indeed composed of self-luminous nebulous matter, or whether they are merely remote, closely crowded, and rounded clusters of stars, they must ever continue to be regarded as highly important features in our knowledge of the arrangement of the structure of the Universe and of the contents of celestial space.

The number of nebulæ whose places in Right Ascension and Declination have been determined already exceeds 3600, and some of those of irregular form and indefinite outline extend over a breadth equal to eight diameters of the moon. According to a former estimate of William Herschel (made in 1811), at least $\frac{1}{270}$ of the entire surface of the heavens is occupied by nebulæ. Seen through colossal telescopes their contemplation leads us into regions from whence, according to no improbable assumptions, a ray of light requires millions of years ere it can reach our eyes,—to distances for which the dimensions of the nearest sidereal stratum (distances of Sirius, or the calculated distances of the double stars in Cygnus and Centaurus), scarcely afford an adequate unit of measure. Supposing the well-defined nebulæ to be elliptical or spherical clusters of stars, then their "conglomeration" itself indicates the existence of some mysterious mode of action in the gravitating forces whose influence they obey. If, on the other hand, they are vaporous masses having one or more nebulous nuclei, then the difference of the degree of condensation exhibited tells us of the possi-

bility of a process of gradual formation of stars from unconsolidated matter. No other class of cosmical forms, no other objects of contemplative rather than of measuring astronomy, are so highly fitted to engage and exercise the power of imagination, not simply as a symbolical image of the infinite in space, but also because the examination of different states or forms of being, and their conjectural connection as stages of existence at successive periods of time, hold out a hope of insight into an antecedent process of formation ([360]).

The historical development of our present degree of knowledge respecting nebulæ teaches us that in this as in almost all other departments of natural knowledge, the same opposite opinions which are now supported by numerous adherents were long ago similarly defended, although on much feebler grounds. Since the general employment of telescopes, we see Galileo, Dominique Cassini, and the sagacious John Mitchell, regarding all nebulæ as remote groups or clusters of stars; while, on the other hand, Halley, Derham, Lacaille, Kant, and Lambert, maintained the existence of starless nebulous masses. Kepler, (as well as, previous to the application of telescopic vision, Tycho de Brahe), was a zealous supporter of the theory of the formation of stars from cosmical nebulous matter, by the condensation of celestial vapours into spherical bodies. He believed, "cœli materiam tenuissimam" (the nebulosity which shines in the Milky Way with a mild sidereal light) "in unum globum condensatam stellam effingere;" he based his opinion not on a process of condensation taking place in the well-defined, rounded nebulæ, for these were unknown to him, but on the sudden shining forth of new stars on the margin of the Galaxy.

The history of our knowledge of nebulæ, if we regard principally therein the number of discovered objects, their thorough examination by the telescope, and an extensive generalization of views, may, like that of double stars, be said to begin with William Herschel. Until his time there were in both hemispheres (including Messier's meritorious labours), only 120 unresolved nebulæ whose positions were determined; whilst as early as 1786, the great Astronomer of Slough published his first catalogue containing 1000. I have noticed in detail in the earlier part of this work that what were called by Hipparchus and Geminus in the Catasterisms of the Pseudo-Eratosthenes, and by Ptolemy in the Almagest, "nebulous-stars," (νεφελοειδεῖς), are clusters of telescopic stars, which, seen by the naked eye, have the appearance of patches of nebulous light ([361]). The same appellation, under the Latinised form of "Nebulosæ," passed in the middle of the 13th century into the Alphonsine Tables; probably through the predominating influence of the Jewish Astronomer, Isaac Aben Sid Hassan, chief of the wealthy synagogue at Toledo. The Alphonsine Tables first appeared in print at Venice in 1483.

We find in an Arabian astronomer of the middle of the tenth century, Abdurrahman Sufi, of Irak in Persia, the first notice of what is now known to be a wonderful assemblage consisting of a countless host of true nebulæ interspersed with star clusters. The "White Ox" which Abdurrahman saw shining with a milky brightness far down below Canopus, was doubtless the larger Magellanic Cloud, which has an apparent breadth of almost twelve diameters of the moon, and covers a space of 42 square degrees in the heavens; and which is first mentioned by European tra-

vellers at the commencement of the 16th century, although Northmen had advanced along the West Coast of Africa as far as Sierra Leone in $8\frac{1}{2}°$ N. lat. nearly two hundred years before (362). It might have been expected that a shining nebulous mass of such great extent, and perfectly visible to the unassisted eye, would have sooner attracted attention (363).

The first detached nebula which was seen and recognised as such by telescopic observation, and commented upon as being destitute of stars and as being an object of a peculiar kind, was that near the star $\upsilon$ Andromedæ, and which, like the Nubeculæ, is visible to the naked eye. Simon Marius (Mayer of Gunzenhausen in Franconia), who was first a musician and then court mathematician to a Margrave of Culmbach, the same who saw Jupiter's satellites nine days before they were seen by Galileo, (364) has also the merit of having given the first, and, indeed, a very accurate description of a nebula. In the preface to his Mundus Jovialis, (365) he relates that, on the 15th of December, 1612, he discovered a fixed star different in appearance from anything which he had ever before seen. It was situated near the third and northernmost star in the girdle of Andromeda: seen with the unassisted eye it appeared only like a small cloud, and viewed through the telescope he could find in it nothing resembling stars; in which respect it differed from the nebulous stars in Cancer, and from other nebulous groups. All that could be distinguished was a white shining appearance, brighter in the centre and fainter towards the margin. The whole, which was about a fourth of a degree in breadth, resembled a light seen from a distance shining through semi-transparent horn (as in a lantern): "similis fere splendor apparet, si a longinquo candela arden

per cornu pellucidum de noctu cernatur." Simon Marius goes on to ask himself whether this singular star may be one which has newly appeared: he declines giving any decided reply to his own question, but is struck by the circumstance that Tycho Brahe, who had enumerated all the stars in the girdle of Andromeda, had not spoken of this "nebulosa." Thus, in the Mundus Jovialis, published in 1614, we find, as I have already remarked ([366]), an enunciation of the difference between an unresolvable nebula (unresolvable, that is to say, by the telescopic powers then available),—and a "cluster of stars" (German, "Sternhaufen," French, "Amas d'étoiles"), in which the crowding together of many small stars, each of which taken separately would be invisible to the naked eye, causes an appearance of nebulous light. Notwithstanding the great improvement in optical instruments, the nebula in Andromeda continued for almost two centuries and a half to be regarded, as at the time of its discovery, as starless, until, two years ago, George Bond, at the Transatlantic Observatory of Cambridge in the United States, recognised 1500 small stars within its limits. Although its nucleus is still unresolved, I have not scrupled to class it among star clusters ([367]).

We can only attribute to a singular accident the circumstance that Galileo, who before 1610, when the Sidereus Nuntius appeared, had already occupied himself repeatedly with the constellation of Orion, mentions subsequently in his Saggiatore, when he might have long been acquainted from the Mundus Jovialis with the discovery of the starless nebula in Andromeda, no other nebulæ in the heavens than those which even his feeble optical instruments resolved into clusters of stars. What he terms the

"Nebulose del Orione e del Presepe" are spoken of by himself as nothing but "accumulations (coacervazioni) of a countless number of minute stars" (368). He forms one after another, under the delusive names of Nebulosæ Capitis, Cinguli, et Ensis Orionis, star clusters, in which he rejoices at having discovered 400 previously unenumerated stars in a space of 1 or 2 degrees; nor does he ever speak of any unresolved nebula:—how can it have happened that the great nebula in Orion's sword should have escaped his notice, or failed to rivet his attention? But although it seems probable that Galileo never observed either the large amorphous nebula in Orion, or the round disk of a so-called unresolvable nebula, yet his general views (369) respecting the internal nature of nebulæ were very similar to those to which the greater number of astronomers are now inclined. Like Galileo, Hevelius of Dantzic (a distinguished observer, but who was unfavourable (370) to the use of telescopes in the formation of star-catalogues), no where mentions in his writings the great nebula in Orion. His tables, indeed, scarcely contain as many as 16 nebulæ having their positions determined.

At last, in 1656, Huygens (371) discovered the nebula in Orion's sword, to which, from its extent, its form, and from the number and celebrity of its later investigators, so much importance has attached; and in 1676 Picard was induced to devote to it his diligent attention. Edmund Halley during his visit to St. Helena (1677) first determined the positions of some, though exceedingly few, of the nebulæ of the southern hemisphere, in parts of the heavens not visible in Europe. The strong predilection which the great Cassini (Jean Dominique), entertained for all parts of contemplative astronomy, led him, towards the end of the 17th

century, to undertake a more careful examination of the nebulæ of Andromeda and Orion. He thought that he perceived changes in the latter since the time of Huygens; and that he even discerned in the nebula in Andromeda "stars which cannot be seen with less powerful telescopes." We have reason to believe that he was mistaken in regard to the supposed alterations in the nebula in Orion, but since the remarkable observations of George Bond the same cannot altogether be said in regard to the existence of stars in the nebula in Andromeda. Cassini, it should be remarked, was from theoretic grounds disposed to anticipate such a resolution, since (in direct contradiction to Halley and Derham), he considered all nebulæ to be very remote clusters of stars (372). It is true that he looked upon the faint milky lustre of the object in Andromeda as analogous to that of the zodiacal light, but this last was also regarded by him as composed of a countless multitude of small planetary bodies thickly congregated (373).

Lacaille, during his sojourn in the southern hemisphere (at the Cape of Good Hope, and the Isles of France and Bourbon, 1750—1752), augmented the number of observed nebulæ so considerably that, as has justly been remarked by Struve, "through this traveller's labours more was then known of the nebulæ of the southern heavens than of those visible in Europe." Lacaille moreover attempted not unsuccessfully to arrange the nebulæ into classes according to their apparent forms; he also first undertook, although with little result, the difficult analysis of the two Magellanic clouds (Nubecula major et minor) with their heterogeneous contents.

If we deduct from the other 42 isolated nebulæ which

Lacaille observed in the southern heavens, 14 which can be perfectly resolved into true star-clusters even with low magnifying powers, only 28 remain, while with more powerful instruments, and greater practice and skill in observing, Sir John Herschel succeeded in discovering in the same zone 1500 nebulæ, clusters being similarly excluded.

Unaided, and unguided by any personal observation or experience, and at first unknown to each other ([374]) although tending in very similar directions, Lambert (from 1749) and Kant (from 1755) exercised their imaginations, and speculated with admirable sagacity on nebulosities, detached galaxies, and islands of nebulæ and stars sporadically dispersed in celestial space. Both Kant and Lambert were inclined to the nebular hypothesis, and to the belief of a process of formation continually going forward in space; and even to the idea of the production of stars from cosmical vapour. Le Gentil (1760—1769), long before his distant voyages and disappointment in regard to the observation of the transit of Venus, promoted the study of nebulæ by his own observations on the constellations of Andromeda, Sagittarius, and Orion. He employed the object-glass of Campani of 34 French feet focal length, in the possession of the observatory of Paris. The sagacious John Mitchell, in complete opposition to the ideas of Halley and Lacaille, Kant, and Lambert, declared (as Galileo and Dominique Cassini had done) all the nebulæ to be clusters of stars,—aggregations of very small or very remote telescopic stars, whose existence would assuredly be demonstrated at some future day by the improvement of instruments ([375]). A rich accession to the knowledge of nebulæ,

rich as compared with the slow advances previously made, was next obtained by the persevering diligence of Messier: deducting those previously discovered by Lacaille and Méchain, his catalogue of 1771 contained 66 nebulæ which had never been recorded before. In the poorly provided Observatoire de la Marine (Hôtel de Clugny), his efforts succeeded in doubling the known number of nebulæ in both hemispheres ([376]).

These feeble beginnings were followed by the brilliant epoch of the discoveries of William Herschel and of his son. As early as 1779 the elder Herschel began a regular review of the nebulæ with a 7-foot reflector; in 1787 his great 40-foot telescope was completed; and in three catalogues ([377]) which were published in 1786, 1789, and 1802, he gave the positions of 2500 nebulæ and star-clusters. Until 1785, and even almost until 1791, this great observer appears to have inclined, with Mitchell, Cassini, and now Lord Rosse, to regard nebulæ, to him unresolvable, as exceedingly remote clusters of stars; but between 1799 and 1802, longer occupation with the subject, led him, as formerly Halley and Lacaille, to embrace the nebular hypothesis, and even, with Tycho Brahe and Kepler, that of the formation of stars from the gradual condensation of cosmical vapour. The two views are not, however, necessarily connected with each other ([378]). The nebulæ and clusters observed by Sir Willliam Herschel were subjected by his son, Sir John Herschel, from 1825 to 1833, to a fresh review, in the course of which he added to his father's list 500 new objects, and published in the Philosophical Transactions for 1833 (p. 365 to 481) a complete catalogue of 2307 nebulæ and clusters of stars. This great work contained

all that had been observed in the part of the heavens visible from middle Europe, and in the next immediately succeeding five years (1834 to 1838), we find Sir John Herschel at the Cape of Good Hope examining with a 20-foot reflector the whole of the heavens visible from thence, and thereby adding to the above 2307 nebulæ and star clusters, a fresh list of 1708 positions (379)! Of Dunlop's catalogue of southern nebulæ and clusters (629 in number, observed at Paramatta from 1825 to 1827 with a 9-foot reflector (380) having a mirror of 9 inches diameter), only one-third were transferred to Sir John Herschel's work.

A third great epoch in the knowledge of these mysterious celestial objects has been commenced by the construction of the admirable 50-foot telescope (381) of the Earl of Rosse at Parsonstown. All the questions which had been agitated in the long course of fluctuating opinions, and in the different stages of development in cosmical contemplation, now became afresh the subjects of animated discussion in the controversy between the nebular hypothesis and the asserted necessity of relinquishing that hypothesis altogether. From the accounts which I have been able to collect on the authority of distinguished astronomers long conversant with the nebulæ, it appears that out of a great number of objects hitherto supposed to be unresolvable, taken as it were by chance from all classes of such objects in the catalogue of 1833, almost all (Dr. Robinson, the Director of the Observatory of Armagh, gives above 40), were completely resolved (382). Sir John Herschel expresses himself in a similar manner in his opening speech at the Meeting of the British Association at Cambridge in 1845, as well as in the Outlines of Astronomy in 1849. He says: "the reflector of Lord

Rosse has resolved, or shown to be resolvable, multitudes of nebulæ which had resisted the space-penetrating power of feebler optical instruments. Although there may be nebulæ which this powerful telescope of six English feet aperture shows only as nebulæ, without any indication of resolvability, yet from inferences founded on analogy we may conjecture that in reality no difference exists between nebulæ and clusters of stars" (383).

The constructor of the powerful optical apparatus at Parsonstown, always carefully separating the result of actual observation from inferences for which it might be hopefully considered that a foundation had been laid, expresses himself with great caution on the subject of the nebula in Orion. In a letter to Professor Nichol of Glasgow, dated March 19, 1846, (384) Lord Rosse wrote:—"From our examination of this celebrated nebula, I can certainly say that very little, if any, doubt remains as to its resolvability. From the state of the atmosphere we could only use half the magnifying power which the mirror is capable of bearing; and yet we saw that everything round the trapezium forms a mass of stars. The rest of the nebula is also rich in stars, and has quite the character of resolvability." At a later period, 1848, Lord Rosse still refrained from announcing the actual achievement of a complete resolution of the nebula in Orion, expressing only the near hope and well-grounded probability of the remaining portion of nebulosity being so resolved.

If, in the animated debate recently awakened respecting the non-existence of a self-luminous nebulous matter in the Universe, we separate what belongs to observation and what to inductive conclusions, a very simple consideration

is sufficient to show that by the increasing perfection of telescopic vision the number of unresolved nebulæ may, indeed, be considerably diminished, but that it is very improbable that the diminution should ever proceed to actual exhaustion. By the successive employment of telescopes of increasing power, each in its turn may be expected to resolve nebulæ which its predecessor had left unresolved; but it will at the same time,(385) by its increased space-penetrating power, replace, at least in part, the resolved nebulæ by new ones previously inaccessible to our view. Thus, by increasing optical power, resolution of old, and discovery of new, would follow each other in an endless succession. Should this not be so, we must, it appears to me, either imagine occupied space to have a limit, or else suppose that the world-islands, to one of which we belong, are so distant from each other that no telescope which may hereafter be invented can ever suffice to reach the opposite shore, and that our last (extremest, or outermost) nebulæ will be resolved into clusters of stars, projected, like the stars in the Milky Way, upon a black ground wholly without nebulosity (386). But it may be fairly asked, whether we can with probability assume both such a state of the Universe, and such a degree of improvement in optical instruments, that in the whole firmament there shall not remain one unresolved nebula?

The hypothetical assumption of a self-luminous fluid presenting itself in well-defined nebulæ, round or oval, must not be confounded with the similarly hypothetical assumption of a non-luminous ether pervading universal space, and producing by its undulations light, radiant heat, and electro-magnetism (387). The emanations from the nuclei of comets, which as comet-tails often occupy enormous portions of

space, disperse the to us unknown matter of which they consist among the planetary orbits of the solar system which they traverse; but when separated from the head or nucleus of the comet, the matter of which the tails are formed ceases to be sensibly luminous to our eyes. Newton considered it possible that "vapores ex Sole et Stellis fixis et caudis Cometarum" might become mingled with the atmosphere which surrounds the Earth [388]. No telescope has yet discovered anything resembling stars in the vaporous flattened revolving ring of the zodiacal light. Whether the particles of which this ring consists,—and which in accordance with dynamic conditions are imagined by some to have rotations independent of the sun, and by others to revolve simply round that body,—shine by reflected light, or whether, like many terrestrial fogs and vapours, [389] they are self-luminous, remains undecided. Dominique Cassini believed them to be small planetary bodies [390]. We feel as it were involuntarily impelled to look in all fluids for detached [391] molecular parts, like the full or hollow vesicles in clouds; and the gradations of increasing density in our solar system from Mercury to Saturn and Neptune, (from 1·12 to 0·14: the Earth being taken as = 1,) conduct us to comets, through the outermost strata of whose nuclei faint stars are visible: they even conduct us gradually to detached particles so rare that the forms of their aggregation can scarcely be said to possess definite outlines.

It was these very considerations on the constitution of the apparently nebulous zodiacal light, which, long previous to the discovery of the small planets between Mars and Jupiter, and before the formation of conjectures respecting meteoric asteroids, led Cassini to entertain the idea of cos-

mical bodies of all dimensions and of all degrees of density. We touch here almost involuntarily on the ancient dispute in philosophy on primitive fluidity and composition from distinct molecular particles, which is indeed more accessible to mathematical treatment. Let us hasten to return to that which is purely objective in the phenomenon.

Among 3926 (2451+1475) recorded positions, [belonging:—*a*, to the portion of the firmament visible at Slough, and which for the sake of brevity we will here call the northern heavens, (according to three catalogues of Sir William Herschel, from 1786 to 1802, and the above-mentioned review published by his son in the Phil. Trans. for 1833); *b*, to the part of the southern heavens visible from the Cape of Good Hope, according to the African Catalogue of Sir John Herschel,] there are contained both nebulæ and clusters of stars. However intimately these objects may in truth be related to each other, yet in order to mark the state of our knowledge at a definite epoch I have reckoned each class separately. I find (392) in the northern catalogue, 2299 nebulæ and 152 clusters of stars; in the southern or Cape catalogue, 1239 nebulæ and 236 star-clusters. This makes for the whole firmament the number of nebulæ registered in these catalogues as not having yet been resolved into stars, 3538. This number would be raised to 4000 by taking into the account three or four hundred objects seen by the elder Herschel (393) and not redetermined by his son, as well as 629 observed at Paramatta by Dunlop with a 9-inch Newtonian reflector, and of which only 206 were transferred by Sir John Herschel to his catalogue (394). A similar result has also been very recently published by Bond and by Mädler. Accord-

ing to the present state of our knowledge, therefore, the proportion of the number of nebulæ to that of double stars is about as 2 : 3; but it should not be forgotten, that under the denomination of double stars are included those which are merely optically double, and that up to the present time changes of position have only been recognised in an eighth, or perhaps even a ninth part of the whole ([395]).

The numbers found above, viz. 2299 nebulæ with 152 star-clusters in the northern, and only 1239 nebulæ with 236 clusters in the southern catalogues, shew a comparatively smaller number of nebulæ and a preponderance of star-clusters in the southern hemisphere. Even assuming the probability of all nebulæ being truly in their own nature alike resolvable, *i. e.*, of their being either more remote clusters, or groups composed of smaller, less crowded, self-luminous cosmical bodies, yet this apparent contrast, (to the importance of which Sir John Herschel himself called attention, ([396]) and that the more strongly as he had employed reflecting telescopes of equal power in the two hemispheres), must at least be held to indicate a striking diversity in distribution in space, *i. e.* in respect to the directions in which they present themselves on the northern or southern firmament to the inhabitants of the earth.

We owe to the same great observer the first exact knowledge and general cosmical view of the distribution of nebulæ and star-clusters over the entire surface of the heavens. In order to examine their situation, their relative abundance in different parts, and the probability or improbability of their succession in certain groupings or lines, he entered between three and four thousand objects graphically in squares of which the sides corresponded to 3° of Declination and

15m of Right Ascension. The greatest local accumulation is found in the northern hemisphere, distributed through the constellations of Leo and Leo minor, the body, tail, and hind-paws of Ursa major, the nose of Camelopardalis, the tail of Draco, the two Canes venatici, Coma Berenices (where the north pole of the Milky Way (397) is situated), the right foot of Böotes, and above all in the head, wings, and shoulders of Virgo. This zone, which has been called the nebula-region of Virgo, contains, as I have already remarked, in a space (398) occupying the eighth part of the entire celestial sphere, one-third of the whole of the nebulæ. It extends but little beyond the equator, excepting where at the southern wing of Virgo it stretches as far as the extremity of Hydra and to the head of Centaurus, but without touching the feet of the Centaur or the Southern Cross. Another and less considerable assemblage of nebulæ in the northern hemisphere, and which Sir John Herschel calls the nebula-region of Pisces, extends further into the southern hemisphere than does that of Virgo. It forms a zone running from the constellation of Andromeda, which it fills almost entirely, to the breast and wings of Pegasus, the band which unites the two Pisces, the southern galactic Pole, and Fomalhaut. A striking contrast to these well-filled regions is presented by the almost desert space, as respects nebulæ, which surrounds Perseus, Aries, Taurus, the head and upper parts of the body of Orion, Auriga, Hercules, Aquila, and the whole constellation of Lyra (399). If, in the general view of the nebulæ and star-clusters belonging to the Northern Catalogue (that of Slough), given in Sir John Herschel's work on the Cape Observations, and where they are distributed into the several hours of Right Ascension, we

combine them into six groups each of four hours, we obtain :—

| | Hours. | | Hours. | |
|---|---|---|---|---|
| R. A. | 0 | to | 4 | 311 |
| | 4 | „ | 8 | 179 |
| | 8 | „ | 12 | 606 |
| | 12 | „ | 16 | 850 |
| | 16 | „ | 20 | 121 |
| | 20 | „ | 24 | 239 |

By a more careful separation according to North and South Declination, we find that in the six hours of Right Ascension from nine hours to fifteen hours, there are in the northern hemisphere alone, 1111 nebulæ and clusters of stars,([400]) viz. :—

| | Hours. | | Hours. | |
|---|---|---|---|---|
| From | 9 | to | 10 | 90 |
| | 10 | „ | 11 | 150 |
| | 11 | „ | 12 | 251 |
| | 12 | „ | 13 | 309 |
| | 13 | „ | 14 | 181 |
| | 14 | „ | 15 | 130 |

The true northern maximum of nebulæ is therefore situated between 12h. and 13h., very near the North Galactic Pole. Farther on, between 15h. and 16h., towards the constellation of Hercules, the decrease is so sudden that the number falls from 130 to 40.

In the southern hemisphere we find not only a much smaller number, but also, generally speaking, a much more uniform distribution of nebulæ. Spaces devoid of these celestial phenomena alternate with sporadic nebulæ; with

the exception of one remarkable local assemblage, which is indeed even more crowded than the nebulous region of Virgo in the northern hemisphere; for of the Magellanic clouds, Nubecula major alone comprehends 300 nebulæ. The region around the pole is poor in nebulæ in both hemispheres, but as far as 15° of polar distance it is poorer round the southern than round the northern pole in the proportion of 4 to 7. The present North Pole has a small nebula only 5 minutes distant from it; a similar one, to which Sir John Herschel very properly gives the name of "Nebula Polarissima Australis," (No. 3176 of his Cape Catalogue; R. A., 9h. $27^{m}$ $56^{s}$, N. P. D., 179° 34′ 14″) is still 25 minutes from the South Pole. The comparatively starless desert round the southern pole, and especially the absence of a pole-star visible to the unassisted eye, were the subject of bitter complaint to Amerigo Vespucci and Vicente Yañez Pinzon, when, at the end of the fifteenth century, they advanced far beyond the Equator to Cape St. Augustin, and when Vespucci even supposed that the fine passage of Dante, "Io mi volsi a man destra e posi mente . . .," and the four stars, "Non viste mai fuor ch' alla prima gente" referred to antarctic circumpolar stars ([401]).

Hitherto we have been considering the nebulæ in respect to their number and dissemination on what is called the firmament, an apparent distribution which must not be confounded with the actual distribution in space. From this examination we now pass to their wonderful diversity in individual form. This is sometimes regular, (spherical, elliptical in various degrees, annular, planetary, or resembling a photosphere surrounding a star); and sometimes irregular or amorphous and as difficult of classification as

are the aqueous nebulæ of our atmosphere, the clouds. The normal form ([402]) of the celestial nebulæ is considered to be elliptical or spheroidal. With equal telescopic power, such nebulæ are most easily resolvable into star-clusters when they are most globular; and on the other hand when the compression in one direction and elongation in the other is greatest they are the most difficult of resolution ([403]). We find in the heavens gradually varying forms from round to elliptic more or less elongated. (Phil. Trans., 1833, p. 494, Pl. ix. figs. 19—21.) The condensation of the milky nebulosity is always progressive towards a centre, or as in some cases even towards several central points or nuclei. It is only in the class of round or oval nebulæ that double-nebulæ are known; and in these, as there is no perceptible relative motion of the individuals in respect to each other, (either because no such motion exists, or that it is exceedingly slow), we are without the criterion which would enable us to demonstrate the reality of a mutual relation, and which in the case of double stars we possess for distinguishing those which are physically from those which are merely optically double. (Drawings of double-nebulæ are to be found in the Philosophical Transactions for 1833, figs. 68—71. Compare also Herschel, Outlines of Astronomy, § 878, and Observations at the Cape of Good Hope, § 120.)

Annular nebulæ are among the rarest phenomena with which we are acquainted. In the northern hemisphere, according to Lord Rosse, seven are known to us. The most celebrated annular nebula is the one situated between $\beta$ and $\gamma$ Lyræ (No. 57, Messier; No. 3023 of Sir John Herschel's Catalogue); it was first observed by Darquier at

Toulouse in 1779, when the comet discovered by Bode came into its vicinity. Its apparent magnitude is nearly equal to that of Jupiter's disk, and it is elliptical,—the proportion of its diameters being as 4 to 5. The interior of the ring is by no means black, but rather somewhat illuminated. Sir William Herschel had recognised some stars in the ring, and Lord Rosse and Mr. Bond have now entirely resolved it (404). On the other hand, the fine annular nebulæ of the southern hemisphere, Nos. 3680 and 3686, are perfectly black in the interior of the ring. No. 3686, moreover, is not elliptical but perfectly round (405); all are probably annular or ring-shaped clusters of stars. It is to be remarked that with the increase of optical means, both elliptical and annular nebulæ appear generally less defined in their outlines: in Lord Rosse's telescope the ring-nebula in Lyra even appears as a simple ellipse, having singular diverging thread-like nebulous appendages. It is especially striking to observe the transformation of the nebula which, seen through feebler telescopes, appears simply elliptical, into Lord Rosse's Crab-Nebula.

A class of phenomena less rare than annular nebulæ, but of which Sir John Herschel counts only 25, almost three-fourths being in the southern hemisphere, consists of what are called planetary nebulæ, which were first discovered by William Herschel, and are among the most wonderful of celestial phænomena. They have a most striking resemblance to the disks of planets. In the greater number of instances they are either round or somewhat oval; sometimes with sharply defined boundaries, and sometimes with confused and vaporous edges. The disks of several have a very uniform light; others are "mottled or of a peculiar

texture as if curdled." They never show traces of condensation towards the centre. Five planetary nebulæ have been recognized by Lord Rosse as annular nebulæ with one or two central stars. The largest planetary nebula is situated in the Great Bear, (not far from $\beta$ Ursæ maj.) and was discovered by Méchain in 1781. The diameter of the disk (406) is 2′ 40″. The planetary nebula in the Southern Cross, (No. 3365, Cape Observations, p. 100,) with a disk of scarcely 12″ diameter, has the brightness of a star of between the 6th and 7th magnitudes. The colour of its light is an indigo-blue, and (among nebulæ) this remarkable hue is found also in three objects of a similar form, in which, however, the blue is less intense (407). The blue tint of some planetary nebulæ by no means contradicts the possibility of their being composed of small stars, for we are acquainted with blue stars, not only as forming both members of a pair or double-star, but also in clusters consisting either entirely of blue, or of blue mixed with red and yellow small stars (408).

The question whether the planetary nebulæ are very distant nebulous stars in which the difference between an illuminating central star and a surrounding vaporous envelope escapes our telescopic vision, has been alluded to in an earlier portion of my work (409). May Lord Rosse's giant telescope at length afford the means of investigating the nature of these wondrous planetary vaporous disks! Difficult as it is to form a clear conception of the complicated dynamic conditions under which, in a spherical or spheroidically elliptical cluster of stars, the rotating, congregated suns, becoming specifically denser as the centre is approached, form a system in equilibrium (410), this difficulty becomes

still greater in those circular, well-defined, planetary nebulous disks which show an entirely uniform brightness not increasing towards the centre. Such a state of things seems less compatible with the form of a globe (or with thousands of small stars in a state of aggregation) than with the idea of a gaseous photosphere, which in our sun is supposed to be covered with a thin, untransparent, or at least very faintly illuminated vaporous stratum. May it be that in the planetary nebula the light appears so uniformly distributed only because the difference between the margin and the centre disappears by reason of the great distance?

Among the nebulæ of regular forms, the fourth and last class consists of Sir William Herschel's "nebulous stars;" *i. e.* actual stars surrounded by a milky nebulosity, which is very probably in relation with the central star and dependent on it. Whether the nebulosity which, according to Lord Rosse and Mr. Stoney, appears in some cases quite annular, (Phil. Trans. for 1850, Pl. xxxviii. figs. 15 and 16), should be regarded as self-luminous, and as forming a photosphere as in our sun,—or whether, (as seems less probable), it be merely illuminated by the central sun,—are points on which very different opinions prevail. Derham, and to a certain degree Lacaille, who at the Cape of Good Hope discovered several nebulous stars, believed the stars to be distant from and unconnected with the nebulæ on which they appeared projected. Mairan (1731) appears to have been the first who put forward the opinion of nebulous stars being surrounded with a luminous atmosphere of their own ([411]). There are even larger nebulous stars (for example of the 7th magnitude, as No. 675 of the Catalogue of 1833),

of which the photosphere has two or three minutes diameter (412).

A class of nebulæ very different from those which we have been describing, and which have always at least a faintly marked outline, consists of the larger nebulous masses of irregular form. These are characterised by very various and unsymmetrical shapes, as well as very imperfectly defined and confused outlines. They are mysterious phenomena "sui generis," and are what have principally given occasion to the opinions which have prevailed respecting the existence of cosmical cloud, and of self-luminous nebulous matter dispersed through the celestial regions and similar to the substratum of the zodiacal light. A most striking contrast is presented by viewing some of the irregular or amorphous nebulæ which cover several square degrees of the surface of the heavens, in comparison with the smallest of all the regular isolated oval nebulæ with which we are acquainted, *i. e.* the one situated between the constellations of Ara and Pavo in the southern hemisphere, and which has a luminous intensity equal to that of a telescopic star of the 14th magnitude (113). No two of the unsymmetrical, diffused nebulous masses resemble each other, "but," adds Sir John Herschel, after many years of observation, "they have one important character in common; they are all situated in or very near the borders of the Milky Way"; and may be "regarded as outlying, distant, and as it were detached fragments of the great stratum of the Galaxy" (414). On the other hand, the regular symmetrical and usually well-defined small nebulæ are partly scattered generally over the heavens, and partly crowded into particular regions remote

from the Milky Way; such in the northern hemisphere are the regions of Virgo and Pisces. It is true that the great irregular nebulous mass in the sword of Orion is fully fifteen degrees from the visible margin of the Milky Way; but it may perhaps belong to the prolongation of that branch of the galaxy which runs from $\alpha$ and $\varepsilon$ Persei, and appears to lose itself near Aldebaran and the Hyades, and of which we have already spoken (Vol. iii. p. 128). The finest stars in the constellation of Orion, which gave to it its ancient celebrity, are considered as belonging to the zone of very large, and probably comparatively near, celestial bodies, the prolongation of which forms a great circle passing through $\varepsilon$ Orionis and $\alpha$ Crucis into the southern portion of the Milky Way ([415]).

An earlier and very prevalent opinion ([416]), as to the existence of a galaxy of nebulæ intersecting the galaxy of stars nearly at right angles, does not by any means appear to be confirmed by later and more exact observations on the distribution of the nebulæ of regular form over the vault of heaven ([417]). There are, indeed, as has been already remarked, large assemblages of nebulæ near the northern galactic and a considerable number near the Southern Fish but from the many interruptions which occur we cannot say that we have found a zone of nebulæ passing through these two poles and forming a great circle of the sphere. William Herschel in 1784, at the conclusion of his first treatise on the structure of the heavens, had indeed developed such a view, but doubtfully, and with the caution which became so eminent an investigator of nature.

Of the irregular, or rather unsymmetrical nebulæ, some, (as those in the sword of Orion, near $\eta$ Argûs, and in Sagitta-

rius and Cygnus), are remarkable for their extraordinary size; others, (as Nos. 27 and 51 of Messier's Catalogue), for the peculiarity of their forms.

In regard to the great nebula in the sword of Orion, we have already noticed the circumstance of its never having been mentioned by Galileo, although he had been so much occupied with the stars between the belt and sword ([418]), and had even constructed a map of that region. What he terms Nebulosa Orionis, and which is drawn by him together with Nebulosa Præsepe, is expressly stated by him to be an assemblage of small stars (stellarum constipatarum) in the *head* of Orion. In the drawing in § 20 of the Sidereus Nuncius, which extends from the belt to $\alpha$ Orionis in the right leg, I recognise, above the star $\iota$, the multiple star $\theta$. The magnifying powers employed by Galileo were only from eight to thirty. As the nebula in the sword does not stand by itself, but forms, when viewed through imperfect telescopes, or in an unfavourable state of the atmosphere, a sort of halo round the star $\theta$, it may be that from this circumstance its individual existence and form escaped the notice of the great Florentine observer, who, moreover, was otherwise disinclined to admit or assume the existence of nebulæ ([419]). It was fourteen years after Galileo's death, in the year 1656, that Huygens discovered the great nebula in Orion, and gave a rough drawing of it, which was published in 1659 in the "Systema Saturnium." His own words are:—"Whilst I was engaged in observing, with a refractor of 23-feet focal length, Jupiter's variable belts, a dark central zone in Mars, and some faint appearances in that planet, there was presented to me among the fixed stars a phenomenon which, so far as I am aware, has never been observed before, and can

only be accurately discerned by means of such large telescopes as that which I employ. In the sword of Orion, astronomers enumerate three stars placed very near to each other: as, in the year 1656, I happened to be looking through my telescope at the middle one of the three, I saw, instead of a single star, twelve, which, indeed, with telescopes is nothing extraordinary. Of these stars, three appeared almost in contact, and four others shone as through a bright haze, so that the space around them, as drawn in the accompanying figure, appeared much lighter than the rest of the sky. It happened to be very clear, and was quite dark, so that the appearance was as if there were an opening or interruption (hiatus). I have seen all this repeatedly since, and that up to the present time, so that this wonderful existence, whatever it may be, has probably always its seat there. I never saw anything similar in any other of the fixed stars." (It would seem, therefore, that the nebula in Andromeda, described 54 years earlier by Simon Marius, was either unknown to Huygens, or had excited but little interest in his mind!) "Whatever other objects have been called nebulæ," he adds, "and even the Milky Way when looked at through telescopes, show nothing nebulous, and are merely multitudes of stars crowded together in clusters" ([420]). The animation and vivacity of this first description testify the magnitude and freshness of the impression produced; but how vast is the difference which separates this first graphical representation made in the middle of the 17th century,—and those, a little less imperfect, of Picard, Le Gentil, and Messier,—from the fine drawings of Sir J. Herschel (1837), and of William Cranch Bond, Director of the Observatory of Cambridge in the United States in 1848! ([421]).

The first named of these later astronomers had the great advantage [422] of observing the nebula in Orion, since 1834, with a twenty-foot reflector at the Cape of Good Hope at an altitude of 60°, and of thereby improving still further his earlier drawing of 1824—26 [423]. The positions of 150 stars in the neighbourhood of $\theta$ Orionis, chiefly from the 15th to the 18th magnitudes, were also determined. The celebrated trapezium, which is not surrounded by any nebulosity, is formed of four stars of the 4th, 6th, 7th, and 8th magnitudes. The 4th star was discovered (1666?) by Dominique Cassini, at Bologna [424]; the 5th ($\gamma'$) in 1826, by Struve; and the 6th ($\alpha'$) which is of the 13th magnitude, by Sir John Herschel in 1832. The Director of the Observatory of the Collegio Romano, de Vico, announced at the beginning of the year 1839, that with his large refractor by Cauchoix he had found three more stars inside the trapezium. These stars have not been seen by John Herschel or Bond. The part of the nebula nearest to the almost unnebulous trapezium, and forming in the front part of the head the Regio Huygeniana, is spotty in its appearance, of a granular texture, and has been resolved into stars by the giant telescope of the Earl of Rosse, and by the great refractor of the Observatory of Cambridge, U.S. [425]. Among our modern accurate observers, Lamont at Munich, Cooper in Ireland, and Lassell in England, have determined many positions of small stars. Lamont employed a magnifying power of 1200. Sir William Herschel thought that he had satisfactorily convinced himself, by the comparison of his own observations made with the same instruments from 1783 to 1811, that changes had taken place in the relative brightness and in the outlines of the great

nebula in Orion ([426]). Bouillaud and Le Gentil had asserted the same of the nebula in Andromeda. The continued investigations of the younger Herschel render these, as it was supposed well assured, cosmical alterations, at least exceedingly doubtful.

*Great nebula round η Argûs.*—This nebula is situated in that part of the Milky Way, so distinguished for its brightness, which extends from the feet of the Centaur through the Southern Cross to the middle portion of the constellation of the Ship. The lustre of this region of the heavens is so extraordinary that an accurate observer residing in India, Captain Jacob, remarks, in full accordance with my own experience during four years passed within the tropics, "that such is the general blaze from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young moon" ([427]). The nebula, in the middle of which the star η Argûs, which has become so celebrated on account of the changes of brightness which it has undergone ([428]), is situated, covers above $\frac{4}{7}$ths of a square degree of celestial space. It consists of several amorphous masses of unequal intensity of light, and no where shows that mottled granular appearance which is considered to indicate resolvability. It encloses a singularly shaped vacuity covered with a very faint degree of light, and forming a lengthened lemmiscate-oval. A fine representation of the whole phenomenon, the fruit of two months measurements, is found in the Cape Observations of Sir John Herschel ([429]). This astronomer has determined in the nebula of η Argûs not less than 1216 positions of stars

mostly from the 14th to the 16th magnitude. The stars form a series which is continued far beyond the nebula into the Milky Way, where they are projected against, and detach themselves from, the blackest background of sky. They are, therefore, probably not connected with the nebula itself, and may be very distant from it. The whole of the adjacent portion of the Milky Way is, indeed, so rich in stars (not star-clusters), that between $9^h\ 50^m$ and $11^h\ 34^m$ R. A., there have been found by "star-gauging" 3138 stars on an average to each square degree. This number even rises to 5093 in the "sweeps" for $11^h\ 24^m$ R. A.; being more stars than are visible to the naked eye, (*i. e.* stars from the 1st to the 6th magnitude), for the horizon of Paris or that of Alexandria ([430]).

*The nebula in Sagittarius.*—This nebula is of considerable extent, and, as it were, composed of four distinct masses (R. A. $17^h\ 53^m$ N. P. D. 114° 21′), one of which is again subdivided into three. All are interrupted by places devoid of nebulous appearance, and the whole had been imperfectly seen by Messier ([431]).

*The nebula in Cygnus.*—Consists of several irregular masses, one of which forms a very narrow divided band passing through the double star $\eta$ Cygni. The connection of these very dissimilar nebulous masses by a singular appearance of cellular texture was first perceived by Mason ([432]).

*The nebula in Vulpes.*—Was imperfectly seen by Messier, and is No. 27 of his list; it was discovered on the occasion of the observation of Bode's comet of 1779. The exact determination of the position (R. A. $19^h\ 52^m$, N. P. D. 67° 43′), as well as the first drawing of this nebula, were given by Sir John Herschel. It received the name of

"Dumb-bell" from its apparent shape as seen with a reflector of eighteen inches aperture (Phil. Trans., 1833, No. 2060, fig. 26; Outlines, § 881). The resemblance to a Dumb-bell entirely disappeared when viewed with a 3-feet reflector of Lord Rosse ([433]), for whose recent and important representation of this nebula see Phil. Trans. 1850, Pl. xxxviii. fig. 17. It was resolved by the same telescope into numerous stars, interspersed amongst still subsisting nebulous appearance.

*Spiral nebula in the northern Canis venaticus.*—This nebula was first observed by Messier on the 13th of October, 1773 (on the occasion of the comet discovered by him): it is in the left ear of Asterion, very near the star $\eta$ (Benetnasch) in the tail of the Great Bear, (No 51 Messier, and 1622 of the great Catalogue in the Phil. Trans. 1833, p. 496, fig. 25). It is one of the most remarkable phenomena in the firmament, as well on account of its wonderful configuration, as of the unexpected transforming effect exerted upon its appearance by Lord Rosse's 6-foot speculum. In the 18-inch reflector of Sir John Herschel this nebula appeared globular, and surrounded by a widely detached ring; thus affording as it were an image or counterpart of our sidereal stratum and Milky Way ([434]). In the spring of 1845, however, the great telescope of Lord Rosse transformed the entire object into a luminous spiral, in which the convolutions are not symmetrically disposed, but prolonged in one direction, and the two extremities, one near the centre and the other towards the exterior, terminate in dense, granular, rounded nuclei. Dr. Nichol has published a drawing of this object (the same which was presented by Lord Rosse to the meeting of the British Association at Cambridge in 1845) ([435]); but the most perfect representation is that by Mr. Johnstone Stoney in the Phil.

Trans. for 1850, Part 11, Pl. xxxv. fig. 1, Similar spiral forms are seen in No. 99 Messier with a single central nucleus, and in other northern nebulæ.

We have next to speak in greater detail than could be done in the General View of Nature (436) of an object unparalleled in the entire firmament, and which greatly enhances the picturesque beauty, so to speak, of the southern celestial hemisphere. The two Magellanic clouds (which were probably first called by Portuguese and then by Dutch and Danish navigators, *Cape-Clouds*) (437), arrest the attention of the traveller, as I have myself experienced, in the most forcible manner, by their brightness, their remarkable isolated position, and their revolution at unequal distances round the southern pole. That the name which refers to Magellan's voyage of circumnavigation was not their earliest designation is proved by the express mention and description of these luminous clouds by the Florentine, Andrea Corsali, in his voyage to Cochin, and by Petrus Martyr de Anghiera, Secretary to Ferdinand of Arragon, in his work de Rebus Oceanicis et Orbe Novo (Dec. i. lib. ix. p. 96) (438). Both these notices belong to the year 1515, whereas Pigafetta, who accompanied Magellan, does not mention the "nebbiette" in the journal of the voyage previous to January 1521, when the ship Victoria made her way from the Patagonian Strait into the South Pacific Ocean. The older name of "Cape-Clouds" is certainly not to be attributed to the proximity of the still more southern constellation of the Table-Mountain, which was itself only introduced by Lacaille. The name may more probably refer to the real Table-Mountain, and to the phenomenon, long dreaded by seamen as portending tempest, of a small cloud

resting on its summit. We shall see presently that the nubeculæ of the southern heavens, after having long been noticed but without receiving any name, as navigation extended and commercial routes became more frequented, gradually obtained names derived from those routes.

The frequent navigation of the Indian sea adjacent to the shores of Eastern Africa, especially from the time of the Ptolemies and in the voyages in which advantage was taken of the Monsoons, first made navigators acquainted with the constellations near the southern pole. As has been already remarked, it is among the Arabians that we find as early as the middle of the tenth century, a name for the larger of the Magellanic clouds which Ideler has identified with the (white) Ox, el-bakar, of the celebrated astronomer Dervish Abdurrahman Sufi of Raï, a town in the Persian Irak. In the "Introduction to the Knowledge of the Starry Heavens," written at the Court of the Sultans of the Dynasty of the Buyides, he says:—"Below the feet of Suhel" (it is expressly the Suhel of Ptolemy, Canopus, which is here meant, although the Arabian astronomers also gave the name of 'Suhel,' to several other large stars in the constellation of "el Sefina" or the Ship), "there is a white patch, which is not seen either in Irak," (in the region of Bagdad), "nor in Nedschd," (Nedjed, the northern and more mountainous part of Arabia), "but is seen in southern Tehama, between Mecca and the point of Yemen, along the shore of the Red Sea" (439). The position of the "White Ox" relatively to Canopus is here assigned with sufficient accuracy for the unassisted eye; for the Right Ascension of Canopus is $6^h$ $20^m$, and the eastern margin of the larger Magellanic cloud is in $6^h$ $0^m$ Right Ascension. The visibility of

the nubecula major in northern latitudes cannot have been materially altered since the tenth century by the precession of the equinoxes, for in the course of the next ten centuries it reached its maximum distance from the north. Taking the most recent determination of the place of the larger cloud by Sir John Herschel, we find that in the time of Abdurrahman Sufi it was perfectly visible as far north as 17° N. Lat.; at present it is so nearly to 18°. The nubeculæ might therefore have been seen throughout the whole of the south-west of Arabia, the incense-producing country of Hadhramaut, as well as in Yemen, the ancient seat of civilization of Saba and of the early immigration of the Joctanides. The extreme southern point of Arabia, at Aden on the Straits of Bab-el-Mandeb, is in 12° 45′, and Loheia is only in 15° 44′ North Lat. The rise of many Arab settlements on the intertropical east coast of Africa, both north and south of the equator, also naturally led to a more complete and detailed acquaintance with the southern constellations.

Of civilised navigators, the first who visited the West Coast of Africa beyond the Line were Europeans, and first, and more especially, Catalonians and Portuguese. Undoubted documents, *i. e.* the Map of the World of Marino Sanuto Torsello, of the year 1306; the Genoese "Portulano Mediceo" of 1351; the "Planisferio de la Palatina," 1417; and the "Mappamondo" of Fra. Mauro Camaldolese, between 1457 and 1459, shew that 178 years before the reputed first discovery of the Cabo Tormentoso (the Cape of Good Hope) by Bartholomew Dias, in the month of May 1487, the triangular configuration of the southern extremity of the African continent was already known (440). After Gama's expedition, the rapidly increasing importance of the commercial route

round the Cape, forming the general object of all voyages along the western coast of Africa, led to the two clouds or nubeculæ being called by navigators the "Cape Clouds," as being remarkable celestial phenomena seen in Cape voyages.

On the east coast of America, the continued attempts to advance southward beyond the equator, and even to the southern extremity of the continent, from the expedition of Alonso de Hojeda, which Amerigo Vespucci accompanied in 1499, to the expedition of Magellan with Sebastian del Cano in 1521, and that of Garcia de Loyasa ([441]) with Francisco de Hoces in 1525, had the effect of continually directing the attention of navigators to the southern constellations. According to the journals which we possess, and to the historical testimonies of Anghiera, this was especially the case in the voyage of Amerigo Vespucci and Vicente Yañez Pinzon, in which Cape St. Augustin, in 8° 20′ S. Lat. was discovered. Vespucci boasts of having seen three Canopuses (one dark, "Canopo fosco," and two "Canopi risplendenti"). According to the attempt made by Ideler, the ingenious author of works on Sidereal Nomenclature and on Chronology, to elucidate Vespucci's very confused description of the southern heavens in his letter to Lorenzo Pierfrancesco de Medici, Amerigo must have used the word "Canopus" in a manner as vague as did Arabian astronomers the word "Suhel." Ideler shows that the "Canopo fosco nella via lattea," was no other than the black spot, or large "coal-bag," in the southern cross; and that the position of three stars supposed to be identified with $\alpha$, $\beta$, and $\gamma$ of the constellation of Hydrus, renders it highly probable that the "Canopo risplendente di notabile grandezza," was the

nubecula major, and the second "Canopo risplendente," the nubecula minor (442). It seems surprising that on becoming acquainted with these new celestial objects Vespucci should not have compared them, as at first sight all other observers have done, to "clouds": such a comparison appears to present itself almost irresistibly. Petrus Martyr de Anghiera, who was personally acquainted with all the discoverers of that remarkable epoch, and whose letters are written under the vivid impression received by him from their narrations, depicts in an unmistakeable manner the mild but unequal light of the nubeculæ: he says, "Assecuti sunt Portugallenses alterius poli gradum quinquagesimum amplius, ubi punctum (polum?) circumeuntes *quasdam nubeculas* licet intueri, veluti in lactea via sparsos fulgores per universi coeli globum intra ejus spatii latitudinem" (443). The great celebrity and long duration of Magellan's voyage of circumnavigation (from August 1519 to September 1522), and the length of time during which the numerous party belonging to it remained under the southern heavens, obscured the remembrance of earlier observation, and the name of "Magellanic clouds" extended itself among the maritime nations bordering on the Mediterranean.

We have taken a single example of the manner in which the extension of the geographical horizon towards the South opened a new field to contemplative astronomy. Navigators advancing under these new heavens felt peculiar interest and curiosity in four objects:—the search after a southern pole-star; the form of the Southern Cross, with its upright position when passing the meridian of the place of observation; the Coal-bags; and the revolving luminous clouds. From Pedro de Medina's "Arte de Navegar" (lib. v.

cap. 11), which appeared first in 1545, and was translated into many languages, we learn that as early as the first half of the sixteenth century meridian altitudes of the "Cruzero" were employed in determinations of latitude: measurement, therefore, soon followed simple contemplation. The first examination into the position of stars near the Antarctic pole was made by means of distances from known stars whose places had been determined by Tycho Brahe in the Rudolphine Tables: the credit of it belongs, as has been already remarked (444), to Petrus Theodori of Emden, and Friedrich Houtman of Holland, who sailed over the Indian seas in 1594. The results of their measurements were soon adopted in the star-catalogues and celestial globes of Blaeuw in 1601, Bayer in 1603, and Paul Merula in 1605. These were the feeble commencements of investigations into the topography of the southern heavens previous to Halley (1677), and previous to the meritorious astronomical endeavours of the Jesuit Jean de Fontaney, of Richaud, and of Noël. The histories of astronomy and of geography, in intimate connection with each other, bring before us the same memorable epochs as conducive alike to the completion of the general cosmical picture of the firmament, and of the outlines of the terrestrial continents.

The two Magellanic clouds, of which the larger covers forty-two and the smaller ten square degrees of the celestial vault, produce at first sight, as seen by the naked eye, the same impression as would be made by two detached bright portions of the Milky Way of corresponding dimensions. In strong moonlight the smaller cloud disappears entirely, while the larger one only loses a considerable portion of its light. The drawing given of them by Sir John Herschel

is excellent, and accords perfectly with my most vivid Peruvian recollections. It is to the arduous exertions of the same astronomer at the Cape of Good Hope in 1837, that we owe the first accurate analysis of these wonderful aggregations of the most various elements ([445]). He found therein single scattered stars in great number; groups of stars and globular star-clusters; and both regular oval, and irregular amorphous nebulæ, more closely crowded than in the nebular zone of Virgo and Coma Berenicis. From the complex character of the nubeculæ, therefore, they ought not to be regarded either (as is too often done) as extraordinarily large nebulæ, or as detached portions of the Milky Way. In the Milky Way, round star-clusters, and more especially oval nebulæ, are extremely rare phænomena ([446]), excepting in a small zone situated between the constellation of Ara and the tail of Scorpio.

The Magellanic clouds are neither connected with each other nor with the Milky Way by any perceptible nebulous appearance. The smaller nubecula is situated in what, excepting the vicinity of the star-cluster in Toucani ([447]), is a kind of starless desert; the larger Magellanic cloud is in a less scantily furnished part of the celestial vault. The structure and internal arrangement of the larger nubecula are so complicated, that masses are found in it (like No. 2878 of Herschel's Catalogue), in which the general form and character of the entire cloud are exactly repeated. The conjecture of the meritorious Horner, of the nubeculæ having once been parts of the Milky Way, in which their former places can still be recognised, is nothing more than a myth; nor is the assertion of a progressive motion or change of position being perceptible in them from the time of Lacaille,

better founded. The indefiniteness of their edges as seen in telescopes of small aperture had caused the positions formerly assigned to them to be inexact, and it has even been remarked by Sir John Herschel that nubecula minor is entered almost one hour in Right Ascension out of its true place in celestial globes and star maps generally. According to the same authority, nubecula minor is situated between the meridians of $0^h\ 28^m$ and $1^h\ 15^m$, and between 162° and 165° north polar distance; and nubecula major in $4^h\ 40^m$ —$6^h\ 0^m$ R. A., and 156°—162° N. P. D. Of stars, nebulæ, and clusters, he has given in Right Ascension and Declination no fewer than 919 in the larger, and 244 in the smaller nubecula. In order to distinguish the three classes of objects from each other I have counted up in the list:—

In nubecula major, 582 stars, 291 nebulæ, 46 star-clusters:

In nubecula minor, 200 stars, 37 nebulæ, 7 star-clusters.

The smaller number of nebulæ in the nubecula minor is striking; their proportion to the nebulæ in nubecula major being as 1 : 8, while the corresponding ratio of single stars in the two nubeculæ is about as 1 : 3. These tabulated stars, almost eight hundred in number, are mostly of the 7th and 8th magnitudes,—some being between the 9th and 10th. In the midst of the nubecula major there is a nebula noticed as early as by Lacaille, (30 Doradûs, Bode, No. 2941 of Sir John Herschel,) which is without a parallel in any part of the heavens. It hardly occupies $\frac{1}{500}$th of the area of the entire nubecula, and yet within this space

Sir John Herschel has determined the positions of 105 stars from the 14th to the 16th magnitude, which are projected against or detach themselves from the altogether unresolved, uniformly shining, and unchequered nebulous ground (448).

Opposite to the Magellanic luminous clouds, and at a greater distance from the Southern Celestial Pole, there revolve around it the black spots or patches which at an early period, at the end of the fifteenth and beginning of the sixteenth centuries, attracted the attention of Portuguese and Spanish Navigators. They probably constitute, as already noticed, the "Canopo fosco" spoken of by Amerigo Vespucci, in his third voyage, among the "three Canopuses" of which he makes mention. I find the first certain indication of these spots in the first Decade of Anghiera's work, "De rebus Oceanicis." (Dec. 1, lib. ix., ed. 1533, p. 20, b.) "Interrogati a me nautæ qui Vicentium Agnem Pinzonum fuerant comitati (1499), an antarcticum viderint polum: stellam se nullam huic arcticæ similem, quæ discerni circa punctum (polum?) possit cognovisse inquiunt. Stellarum tamen aliam, ajunt, se prospexisse faciem densamque quandam ab horizonte vaporosam caliginem, quæ oculos fere obtenebraret." The word "stella" is here taken to mean generally a celestial form or object, and the narrators may have expressed themselves rather indistinctly respecting a "caligo" which "darkens the eyes." Pater Joseph Acosta of Medina del Campo speaks in a more satisfactory manner respecting the black patches and the cause of their appearance. In his Historia Natural de las Indias (lib. i. cap. 2,) he compares them, in respect to colour and form, to the dark part of the moon's disk. "As," said he,

"the Milky Way appears bright because it consists of denser celestial matter, and therefore radiates more light, so the *dark patches which are not seen in Europe* are entirely without light, because they form a region of the heavens which is void, *i. e.*, composed of very rare and highly transparent matter." That a celestial astronomer should have identified this description with the solar spots (449) is no less strange than that the missionary Richaud (1689) should have taken Acosta's "Manchas negras" for the luminous Magellanic Clouds (450).

Richaud, like the oldest navigators, speaks of the "coal-sacks" in the plural; he names two, one in the Cross, and another in Robur Caroli: in other descriptions this last is even divided into two separate spots or patches. These are described by Feuillée in the first years of the 18th century, and by Horner in a letter written to Olbers from Brazil in 1804, as imperfectly defined and with confused edges (451). During my stay in Peru I never could make out in a manner satisfactory to myself the Coal-sacks in Robur Caroli, and being disposed to attribute my want of success to the low altitude of the constellation, I turned for information and instruction on the subject to Sir John Herschel, and to the Director of the Hamburgh Observatory, Hr. Rumker, both of whom had been in much higher southern latitudes. I found that notwithstanding all their endeavours neither of these gentlemen had ever succeeded any more than myself in finding anything which for definiteness of outline or intensity of blackness could be compared to the "Coal-sack" in the Cross. Sir John Herschel thinks that we ought not to speak of a plurality of coal-sacks unless we intend to regard

as such every darker portion of the heavens, even though it may present no definite boundary; (as between $\alpha$ Centauri and $\beta$ and $\gamma$ Trianguli (452), between $\eta$ and $\theta$ Argûs; and especially, in the northern celestial hemisphere, the vacant space in the Milky Way between $\epsilon$, $\alpha$, and $\gamma$ Cygni) (453).

The phenomenon of this class which has been longest known, and which is most striking to the unassisted eye,—viz. the dark patch in the Southern Cross, is situated on the eastern side of that constellation, and is pear-shaped, with a length of 8 and a breadth of 5 degrees. There is in this large space one star visible to the naked eye, (between the 6th and the 7th magnitude), and a large number of telescopic stars from the 11th to the 13th magnitudes. A small group of 40 stars occupies nearly the centre of the space (454). Paucity of stars and contrast with the surrounding brightness have been assigned as the causes of the sensible blackness of the space in question; and since the time of Lacaille (455) this explanation has been generally received. It has been more particularly supported by the results of "star-gauges and sweeps" taken around the space where the Milky Way appears as if covered by a black cloud. With equal fields of view the sweeps gave within the coal-sack from 7 to 9 telescopic stars, (never perfect vacuity or blank fields), while around and beyond the borders from 120 to 200 stars were counted. Whilst I remained under the southern tropic, and under the influence of the powerful impression made upon me by the aspect of the celestial canopy towards which my attention was continually drawn, the above explanation, from the effect of contrast, appeared to me, probably erroneously, to be an

unsatisfactory one. Sir William Herschel's considerations on the quite starless spaces in Scorpio and Ophiucus, which he terms "openings in the heavens," led me to the idea that perhaps in such regions the sidereal strata may be thinner or may even be entirely interrupted; that our optical instruments fail to reach the last strata, and that "we look as through tubes into the remotest regions of space." I have already alluded elsewhere to these "openings" (456); and the effects of perspective on such interruptions in the sidereal strata have very recently formed the subject of grave discussion. (457)

The consideration of the outermost and remotest strata of self-luminous worlds, the distances of nebulæ, and all the subjects which have been crowded into the last of the seven sidereal or astrognostic sections of this work, fill our imagination with images of time and space surpassing our powers of conception. Great and admirable as have been the advances made in the improvement of optical instruments within the last sixty years, we have at the same time become sufficiently familiar with the difficulties of their construction not to give ourselves up to such daring, and, indeed, extravagant hopes, as those with which the ingenious Hooke was seriously occupied between 1663 and 1665 (458). Here, also, we advance further and more securely towards the goal by moderation in our anticipations. Each of the successive generations of mankind is in its turn enabled to rejoice in the greatest and highest results attainable by man's intellect freely exerted from the standing place to which art may then have risen. Without enunciating in determinate numbers the extent of space-pene-

trating power already achieved in telescopic vision, and without laying much stress upon such numbers, still our knowledge of the velocity of light teaches us, that in the faint glimmer proceeding from the self-luminous surface of the remotest heavenly body we have "the most ancient sensuous evidence of the existence of matter ([459])."

## β. *The Solar Domain.*

*Planets and their satellites, comets, ring of zodiacal light, and meteoric asteroids.*

When in the Uranological portion of the physical description of the Universe we descend from the heaven of the fixed stars to our solar and planetary system, we pass from the great and universal to the relatively small and special. The domain of the Sun is the domain of a single fixed star among the myriads which the telescope discloses to our view; it is the limited space within which cosmical bodies of very different kinds, obeying the immediate attraction of one central body, revolve around the same in wider or narrower orbits, either alone or accompanied by other bodies similar to themselves and revolving round them. In the sidereal portion of Uranology which I have attempted to treat in the earlier part of the present volume, I have indeed described among the millions of telescopic fixed stars, one class, that of double stars, which also presents particular systems, either binary or consisting of more than two members; but these, notwithstanding the analogy of their impelling forces, are yet in their nature different from our solar system. In them, self-luminous fixed stars move around a common centre of gravity which is not occupied by visible matter; in the solar system, dark cos-

mical bodies revolve round one which is self-luminous; or, to speak more precisely, round a common centre of gravity, which is sometimes included within, and sometimes falls without, the central body. "The great ellipse which the Earth describes round the Sun is reflected in a small but otherwise entirely similar ellipse, in which the centre of the Sun moves round the common centre of gravity of the Earth and Sun." Whether the planetary bodies, among which the interior and exterior comets must also be included, are not also partially capable of originating light of their own, besides that which they receive from the central body, is a question which in these general indications needs not to be further touched upon.

We have hitherto no direct evidence of the existence of dark planetary bodies revolving round other fixed stars. Should such exist, as was surmised long before Lambert by Kepler, the faintness of reflected light must probably for ever forbid their being seen by the inhabitants of the Earth. If the nearest fixed star, α Centauri, is distant from the Sun, 226,000 semi-diameters of the Earth's orbit, or 7523 semi-diameters of Neptune's orbit,—and if the solar distance of the aphelion of a comet of very wide elongation, that of 1680 (to which, although on very insecure grounds, a period of 8800 years has been attributed), is equal to 28 distances of Neptune,—the distance of α Centauri will still be 270 times more than the extent of our solar domain taken to the aphelion of that most distant comet. We see the reflected light of Neptune at 30 times the distance of the Earth from the Sun: if in more powerful telescopes to be hereafter constructed there should be discovered three more planets at distances successively increasing, so that the

outer one should be a hundred times the Earth's distance from the Sun, this would still not be an eighth part of the distance of the aphelion of the above mentioned comet, or the 2200th part ([460]) of that from which we should have to view the reflected light of a planet or satellite revolving round *α* Centauri. But it may be asked, is the assumption of the existence of planets or satellites revolving round the fixed stars unconditionally necessary. If we glance at the subordinate particular systems within our general planetary system, we find, notwithstanding the analogies which may be presented by those planets round which many satellites revolve, that there are also other planets, Mercury, Venus, and Mars, which have not even a single satellite. If we pass from what is simply possible and confine ourselves to what has been actually investigated, we shall be vividly impressed by the idea that the solar system, especially as the last ten years have disclosed it to us, affords the fullest picture of easily recognised direct relations of many cosmical bodies to one central one.

In the astronomy of measurement and calculation, the more limited space of the planetary system, by reason of this very limitation, offers, as compared with the consideration of the heaven of the fixed stars, incontestable advantages in respect to the evidence and certainty of the results obtained. Much of sidereal astronomy is simply contemplative; it is so in regard to star-clusters and nebulæ, and also the very insecurely grounded photometric classification of the fixed stars. The best assured and most brilliant department in astrognosy, and which in our own time has received such exceeding improvement and enlargement, is

that of the determination of positions in Right Ascension and Declination, whether of single fixed stars, or of double stars, star-clusters, and nebulæ. Measurable relations of a more difficult class, but yet susceptible of a greater or less degree of accuracy, are presented by the proper motion of stars;—the elements by means of which their parallax may be sought;—telescopic star-gaugings, throwing light on their distribution in space;—and the periods of variable stars and slow revolutions of double-stars. Subjects which by their nature escape from the domain of measurement, properly so called, such as the relative position and the forms of sidereal strata or annuli; the arrangement of the structure of the universe; the effects of rapidly transforming natural agencies ([461]) in the blazing forth and speedily succeeding extinction of what have been called new stars, all affect the mind the more vividly and profoundly from the wide scope which they furnish to the fascinating exercise of the imaginative faculties.

We purposely abstain in the following pages from all considerations respecting the connection of our solar system with the systems of the other fixed stars; we do not propose to return to questions respecting the subordination and mutual dependence of different systems,—questions which appear to grow out of what are felt to be intellectual wants; as for example, whether our sun be not itself in a state of planetary dependence on a higher system, perhaps not even as a primary planet, but only as the satellite of a planet, like the moons of Jupiter in our own system. We limit ourselves to the home circle of the solar domain itself; and in doing so we enjoy the advantage that, with the exception of what relates

to the interpretation of the appearance of the surfaces, and to the gaseous envelopes of the different orbs, to the simple or divided tails of comets, the ring of zodiacal light, and the enigma of the phenomenon of meteoric asteroids,—almost all the results of observation are susceptible of reduction to numerical relations, and all present themselves as consequences of assumptions admitting of being brought to the test of strict demonstration.

Such demonstration does not fall within the scope of this "Sketch of a Physical Description of the Universe," but the methodical presentation of the numerical results in a brief and collected form does belong to the plan of such a sketch. These results constitute the rich inheritance which, evermore growing by continual accession, is handed down from one century to another. A table containing the numerical elements of the planets (showing in the case of each planet its mean distance from the sun, its period of revolution, excentricity of orbit, inclination to the ecliptic, diameter, mass, and density), gives in an exceedingly small space the standard of knowledge, or the intellectual height in this respect, to which the age has attained. If we throw ourselves back in imagination for a moment into the times of classical antiquity, and figure to ourselves Philolaus the Pythagorean (the instructor of Plato), Aristarchus of Samos, or Hipparchus, in possession either of a sheet with such a table of numbers, or of a graphical representation of the planetary orbits such as is given in our briefest elementary works, we could only compare the astonishment of these men, the heroes of the earlier more limited knowlege, to that of Erastosthenes, Strabo, or Ptolemy, if one of our maps of the

world, on Mercator's projection, of a few inches in size, could have been placed before them.

The return of comets in closed elliptic orbits, inasmuch as it is the result of the attracting force of the central body, must be held to indicate their comprehension within the boundary of the solar dominion. But since we are uncertain whether comets may not hereafter appear, the major axes of whose ellipses shall be found to exceed in length any of those which have yet been calculated, we can only say that the remotest cometary aphelion with which we are acquainted marks the smallest or least distant limit which can be assigned to the solar system, *i.e.* its minimum extension. We regard the solar system, therefore, as being characterised by the visible and measurable results of central forces acting within the system, and by cosmical bodies (planets and comets) which revolve in closed paths around the sun, and remain attached to it by a direct and positive connection. The attraction exerted by the sun in wider spaces beyond those returning and revolving bodies on other suns or fixed stars, does not belong to the considerations with which we are here engaged.

The solar domain comprehends, according to the state of our knowledge at the close of the first half of the nineteenth century, and arranging the planets in the order of their distances from the central body—

TWENTY-TWO PLANETS. (MERCURY, VENUS, EARTH, MARS; *Flora, Victoria, Vesta, Iris, Metis, Hebe, Parthenope, Irene, Astræa, Egeria, Juno, Ceres, Pallas, Hygiea;* JUPITER, SATURN, URANUS, NEPTUNE.)

TWENTY-ONE SATELLITES. (1 belonging to the

Earth, 4 to Jupiter, 8 to Saturn, 6 to Uranus, 2 to Neptune).

One hundred and ninety-seven *Comets*, whose paths have been calculated: amongst them are 6 interior, *i. e.* whose aphelia are included within the outermost planetary orbit, viz. that of Neptune.

The solar system comprises, besides the above-mentioned bodies, with great probability, the *ring of the Zodiacal Light*, situated perhaps between the orbits of Venus and Mars.

And, according to the opinion of many observers, the *host of meteoric asteroids* which intersect the Earth's path, more especially at particular points.

In the above enumeration of the 22 planets, of which 6 were known previous to the 13th of March 1781, the 8 greater planets are distinguished by larger type from the 14 smaller planets, sometimes called "co-planets," or "asteroids," whose intersecting orbits are situated between Mars and Jupiter.

In the modern history of planetary discoveries, the leading epochs have been the discovery by William Herschel at Bath on the 13th of March, 1781, of Uranus, being the first planet discovered beyond the orbit of Saturn, and recognised as a planet by its disk and by its motion;—the discovery by Piazzi, at Palermo, on the 1st of January, 1801, of Ceres, the first of the smaller planets;—the recognition by Encke, at Gotha, in August 1819, of the first "interior" comet;—and the announcement from calculations of planetary disturbances of the existence of Neptune by Le Verrier, at Paris, in August 1846, as well as its actual discovery by Galle, at Berlin, on the 23d of September of the same year.

Each of these important discoveries has not only had for its direct result the immediate enlargement and enrichment of the solar system as known to mankind, but it has also given occasion to numerous similar discoveries: to the recognition of 5 other interior comets (by Biela, Faye, de Vico, Brorsen, and D'Arrest, between 1826 and 1851; and of 13 small planets, three of which (Pallas, Juno, and Vesta), were discovered between 1801 and 1807, and after an interval of fully thirty-eight years, in rapid succession, following the happy and well-planned discovery of Astræa by Hencke, December 8, 1845, of nine others by Hencke, Hind, Graham, and de Gasparis, from 1845 to the middle of 1851. Attention to comets has so much increased, that in the last eleven years the paths of 33 newly discovered comets have been calculated, being nearly as many as were computed in the course of the forty preceding years of the present century.

# I.

## THE SUN AS A CENTRAL BODY

"The luminary of the World (lucerna Mundi), enthroned in the midst," as Copernicus ([462]) terms the solar orb,—according to Theon of Smyrna ([463]) the "all animating, pulsating heart of the Universe,"—is to our planet the great source of light and radiant heat, and the exciter not only of many terrestrial electro-magnetic processes, but also of the greater part of the processes of organic vital activity, and more especially of those of vegetable life. The Sun, if we desire to indicate its influences and effects with the greatest generality, may be said to produce changes on the surface of the Earth partly by attraction of mass, as in the ebb and flow of the ocean (if we abstract from the whole effect the portion due to lunar attraction); partly by light- and heat-exciting undulations, (transverse vibrations of the ether), operating both directly, and also *by* the fertilising intermixture of the aërial and aqueous envelopes of the planet, effected through the medium of the evaporation of the liquid element from seas, lakes, and rivers. To the solar agency are also due those atmospheric and oceanic currents occasioned by dif-

ferences of temperature, of which the latter have acted for thousands of years, and still continue to act though with less energy, in modifying the form and character of the terrestrial surface,—in some places by abrasion and denudation, in others by the accumulation of transported detritus. The sun's influence operates, moreover, in producing and maintaining the electro-magnetic activity of the crust of the Earth, and of the oxygen contained in the atmosphere; it acts sometimes silently and tranquilly in forces of chemical attraction, and in determining the varied processes of organic life in the endosmose of vegetable cells, and in the texture of muscular and nervous fibres; — and sometimes with more obvious and tumultuous energy, by calling forth in the atmosphere luminous processes, coloured flashing polar light, lightning, hurricanes, and water-spouts.

I have attempted the enumeration in a single brief sketch of the various solar influences, so far as they do not relate to the position of the axis and to the path of our globe, for the sake of bringing vividly into view, by means of the presentation of grand and varied phenomena which at first sight appear so heterogeneous, that character of my work which tends to depict physical nature in this "book of the Cosmos" as a WHOLE, moved, and as it were animated, by internal, often mutually compensating and counterbalancing, forces or powers. But the luminous undulations act not alone on the material world, decomposing and reuniting its substances in fresh combinations,—they do not merely call forth from the bosom of the earth the tender germs of plants, —elaborate in leaves the substance (chlorophyll) to which they owe their verdure, and in flowers their tints and fragrance, —and repeat a thousand, and again a thousand

times, the Sun's bright image in the sparkling play of the waves of the sea, and in the dew-drops on the blades of grass as the breeze sweeps over the meadow ;—the light of heaven, in the various degrees of its intensity and duration, also connects itself by mysterious links with man's inner being,—with his intellectual susceptibilities, and with the cheerful and serene, or the melancholy tone of his disposition :—" Cœli tristitiam discutit Sol et humani nubila animi serenat." (Plin. Hist. Nat. ii. 6).

In describing the several cosmical bodies, I commence in each case with the numerical data belonging to them, and place next whatever inferences the present state of our knowledge may enable us to draw respecting their physical constitution. The arrangement of the numerical results is nearly the same as in Hansen's excellent " Uebersicht des Sonnensystems" ([464]), but with additions and modifications, —inasmuch as, since the year 1837, when Hansen wrote, eleven planets and three satellites have been discovered.

The mean distance of the centre of the Sun from the Earth is, according to Encke's valuable correction of the Sun's parallax (Abhandl. der Berl. Akad. 1835, S. 309), 20682000 (German) geographical miles of 15 to a degree of the terrestrial equator (equal to 82728000 English geographical miles), each German mile containing according to Bessel's examination of ten measured (Kosmos, Bd. i. S. 421, Eng. Ed. p. xlii., Note 130), precisely 3807.23 toises, or 22843·33 Paris feet; (in English measure 6086·76 British feet to a British geographical mile 60 to a degree.)

According to Struve's observations of aberration, light takes to reach the Earth from the Sun, or, in other words, to traverse the semi-diameter of the Earth's orbit, 8′ 17″.78

(Kosmos, Bd. iii. s. 91, and 127 Anm. 52, Eng. ed. p. 73, and Note 140), whence the true place of the Sun is 20″.445 in advance of the apparent place.

The apparent diameter of the Sun at its mean distance from the Earth is 32′ 1″.8 : only 54″.8 more than the apparent diameter of the disk of the Moon at her mean distance from the Earth. At our perihelion, in the winter when we are nearest to the Sun, its apparent diameter is increased to 32″ 34″.6 ; at the aphelion in the opposite part of the year, when we are farthest from the Sun, its apparent diameter is diminished to 31′ 30″.1.

The true diameter of the Sun is 192700 German, or 770800 English geographical miles ; or, more than 112 times greater than the diameter of the Earth.

The mass of the Sun is, according to Encke's calculation of Sabine's pendulum formula, 359551 times that of the Earth, or 355499 times the mass of the Earth and Moon taken together (Vierte Abh. über den Cometen von Pons in den Schr. der Berl. Akad. 1842, S. 5) ; this would make the density of the Sun only about one quarter (more exactly 0·252), of that of the Earth.

The Sun has 600 times more volume, and according to Galle, 738 times more mass, than all the planets together. In order to convey in some degree a sensible image of the magnitude of the body of the Sun, it has been remarked that if we were to imagine the globe of the Sun entirely hollowed out, and the Earth placed in its centre, there would still be room for the Moon's orbit, even though the semi-diameter of the said orbit were to be increased by upwards of 40000 (160000 English) geographical miles.

The Sun rotates round its axis in $25\frac{1}{2}$ days ; its equator

is inclined $7\frac{1}{2}°$ to the Ecliptic. According to Laugier's very careful observations (Comptes rendus de l'Acad. des Sciences, T. xv. 1842, p. 941), the time of rotation is 25.34 days (or 25 days, 8 hours, 9 minutes), and the inclination of the Equator is 7° 9′

The conjectures respecting the physical character of the Sun, at which modern astronomy has gradually arrived, are founded on long and careful observation of changes seen to take place in the luminous disk. The order of succession and the connection of these changes (*i. e.* the apparent formation of the solar spots and the relation of their centres or nuclei of deep black to surrounding ashy grey penumbras), have led to the supposition that the actual body of the solar orb is itself almost entirely dark, but encompassed at a considerable distance by a luminous envelope, in which funnel-shaped openings are produced by the action of currents from below upwards, and that the black nuclei of the spots are portions of the dark body of the Sun seen through these openings. In order to make this explanation (which is here noticed in a cursory manner and only with the greatest generality), account more satisfactorily for the various particulars of the observed phenomena, there are assumed, in the present state of our knowledge, three solar envelopes: first, an inner cloud-like vaporous envelope; over this the luminous envelope (photosphere); and above this again (and as apparently indicated more particularly in the phenomena of the total solar eclipse of the 8th of July, 1842), an external vaporous envelope, either dark or only very faintly illuminated ([465]).

As happy anticipations and imaginations, long antecedent to all actual observation, sometimes contain the germ of true views, (Grecian antiquity is full of instances of such

speculations which after ages have realised), so we find as early as the middle of the fifteenth century, in the writings of Cardinal Nicolaus, of Cusa, in the second book of the treatise "De docta ignorantia," the opinion clearly expressed, that the body of the Sun is only an earthy kernel surrounded by a luminous shell as by a fine veïl, and having in the middle (between the dark kernel and luminous shell?) a mixture of water-bearing clouds and clear air similar to our atmosphere; and that the power of radiating forth the light which animates vegetation on the surface of the Earth belongs not to the earthy kernel or nucleus of the Sun, but to its bright surrounding covering. This view of the physical constitution of the Sun, which has hitherto attracted so little notice in the history of astronomy ([466]), has a great resemblance to the views which prevail at the present time.

I have shown in an earlier volume, in the notice of "historical epochs in the physical contemplation of the Universe" ([467]), that the spots on the Sun were first seen and described in print, not by Galileo, Scheiner, or Harriott, but by Johann Fabricius of East Friesland. Both the discoverer, and also Galileo, as is shown by his letter to the Principe Cesi, written on the 25th of May, 1612, knew that the solar spots belonged to the Sun itself; nevertheless, ten and twenty years later, a Canon of Sarlat, Jean Tarde, and a Belgian Jesuit, maintained that the spots were transits of small planets: by the one called Sidera Borbonia, and by the other Sidera Austriaca ([468]). Scheiner was the first to adopt the use in observations of the Sun of the blue and green shade-glasses ([469]) which had been suggested 70 years before by Apian (Bienewitz), in the "Astronomicum Cæsareum," and had long been made use of by the Belgian navigators; the

non-employment of which had greatly contributed to occasion Galileo's loss of sight.

As elicited by actual observation after the discovery of the solar spots, I find the earliest and most definite expressions as to the necessity of assuming the Sun to be a dark globe surrounded by a luminous envelope (photosphere), from the pen of Dominique Cassini in 1671 ([470]) According to him the solar disk which we see is "a luminous ocean surrounding the solid and dark nucleus of the Sun; tumultuous movements taking place in the luminous envelope allow us from time to time to see the mountain summits of the non-luminous body of the Sun itself. They are the black nuclei in the centre of the solar spots." The ash-coloured penumbras surrounding the nuclei still remained without any attempt at explanation.

An ingenious, and since often confirmed observation, made by Alexander Wilson, the Astronomer of Glasgow, on a large solar spot on the 22d of November, 1769, led him to an explanation of the penumbras. Wilson discovered that as a spot moves towards the Sun's limb, the penumbra on the side towards the centre of the Sun becomes gradually narrower and narrower as compared wtth that on the opposite side. He inferred, very justly, from the ratios of these dimensions, that the nucleus of the spot (the part of the dark body of the Sun becoming visible through the funnel-shaped excavation of the luminous envelope), is situated deeper than the penumbra, and that the penumbra is formed by the steep declivities or side walls of the funnel ([471]). This mode of explanation, however, offered no reply to the question why the penumbra should be lightest near the dark nucleus?

Our Berlin Astronomer, Bode, without being acquainted with the earlier memoir of Wilson, developed, in his peculiarly lucid and popular manner, perfectly similar views, in his "Thoughts on the Nature of the Sun and the origin of its spots" ("Gedanken über die Natur der Sonne und die Enstehung ihrer Flecken"). Bode had also the further merit of having facilitated the explanation of the penumbra by assuming, almost as in the anticipatory conjectures of Cardinal Nicolaus of Cusa, an additional stratum of cloudy vapour between the photosphere and the dark body of the Sun. This hypothesis of two distinct envelopes leads to the following inferences: if, in the smaller number of cases, an opening is formed in the photosphere only, and not at the same time in the inner vaporous stratum which is supposed to be only imperfectly illuminated by the brighter outer one, then this inner envelope will reflect towards the earth only a very mitigated light, and thus there is produced a grey penumbra without any black nucleus. But if in the tempestuous meteorological processes taking place on the surface of the Sun the opening penetrates both envelopes (*i. e.* both the luminous and the cloudy one), then there appears in the ash-coloured penumbra, a nucleus "shewing a more or less intense blackness according to the character of the surface of the body of the Sun at the part exposed by the opening" (472). The shade round the nucleus is a part of the external surface of the inner vaporous stratum, and as the latter, by reason of the funnel shape of the whole excavation, has a smaller opening than the photosphere, so the path of the rays which on both sides pass along the edges of the interrupted strata, and arrive at the eye of the observer, explains the difference first perceived by Wilson to take place gradually in the relative

breadths of the opposite sides of the penumbra, as the distance of the nucleus from the centre of the Sun's disk increases. When, as Laugier has more than once remarked, the penumbra spreads over the black nucleus itself, so that the latter disappears altogether, the cause is that the opening of the inner cloudy envelope is closed, whilst that in the photosphere remains open.

A solar spot visible in 1779 to the naked eye fortunately led the genius of William Herschel, happy alike in observation and combination, to the subject now before us. The results of his great examination, in which the details of several cases are treated according to a very definite nomenclature established by himself, are given in the Philosophical Transactions of 1795 and of 1801. He proceeds as usual in his own manner, and merely names Alexander Wilson once. His view is in its generality identical with that of Bode; his interpretation of the visibility and dimensions of the nucleus and the penumbra (Phil. Trans. 1801, p. 270 and 318, Tab. xviii. fig. 2), is based on the assumption of an opening in two envelopes; but besides these he places between the envelope and the body of the Sun (p. 302), a clear and transparent atmosphere, in which dark clouds (or at least only faintly illuminated by reflection) are suspended at a considerable height,—as three hundred (English) geographical miles. Wm. Herschel seems, indeed, inclined to believe the photosphere also to be only a stratum of unconnected phosphoric clouds with very uneven surfaces. It seems to him that an elastic fluid of an unknown nature rises from the crust or surface of the dark body of the Sun, occasioning in the upper region, when it acts most feebly, only small pores or punctures, and when it acts most energetically and tempes-

tuously, large openings with their dark centres or nuclei surrounded by penumbras or "shallows."

The black nuclei of the solar spots, which are seldom round, but, on the contrary, almost always characterised by corners, jagged edges, and re-entering angles, are often surrounded by penumbras in which the same figure is repeated on a larger scale. There is no perceptible gradual transition from the colour of the nucleus to that of the penumbra, or from the penumbra, which has sometimes a filamentous appearance, to the photosphere. Capocci, and a very diligent observer, Pastorff, (at Buckholz, near Frankfurt on the Oder), have given very exact drawings of the angular forms of nuclei, (Schum. Astr. Nachr. No. 115, S. 316, No. 133, S. 291, and No. 144, S. 471). William Herschel and Schwabe saw the dark nuclei crossed by shining veins of light, and even by, as it were, "luminous bridges,"—phenomena of a cloud-like nature belonging to the second stratum which produces the penumbras. These singular forms, probably the consequences of ascending currents, the tumultuary formation and appearances of spots, faculæ, furrows, and projecting ridges (the crests of luminous waves), are regarded by the astronomer of Slough as indicating powerful evolution of light; while on the other hand he considers the absence of solar spots and their accompanying phenomena to indicate comparative feebleness of combustion, and consequently a less degree of beneficial action on the temperature of our planet and on vegetation. These conjectures led Wm. Herschel to attempt to bring into comparison and connection the absence of solar spots in the years 1676—1684 (according to Flamstead); from 1686 to 1688 (according to Dominique Cassini); from

1695 to 1700; and from 1795 to 1800; with the prices of corn and the complaints which had been made of bad harvests ([473]). Unfortunately, however, the knowledge of the numerical elements required to furnish the base of even a conjectural solution of such a problem must always be wanting; not only, as Herschel himself justly remarked, because the price of corn in one part of Europe cannot afford a standard whereby to judge of the state of vegetation over the whole continent, but also and more especially, because we can by no means infer from a diminution of the mean temperature of the year extending even over the whole of Europe, that in that year the globe generally had received a less quantity of warmth than usual from the Sun. Dove's investigations on the non-periodic variations of temperature have tended to show that "oppositions," or contrary states of weather, are always placed laterally side by side, in the same, or almost the same, parallels of latitude. Thus our continent and the temperate part of North America are usually opposed to each other in this respect, so that if we have an abnormally severe winter, the winter there will be milder than in ordinary years, and *vice versâ*. Seeing the unquestionable influence of the mean amount of summer heat on the cycle which vegetation passes through, and therefore on the success of cereal crops, we must regard such compensations in the distribution of temperature, over parts of the globe united by easy and convenient communication by sea, as productive of highly beneficial consequences to mankind.

While William Herschel attributed to the activity of the central body, manifested in the processes of which the solar spots are results, the effect of an increase in the temperature

of the Earth, Batista Baliani, nearly two centuries and a half before, in a letter to Galileo, described these spots as cooling agencies ([474]). A similar inference has been drawn from the essay made by the diligent astronomer Gautier at Geneva ([475]), to compare four periods of frequency and paucity of spots on the sun's disk (from 1827 to 1843) with the mean temperatures shewn by 33 European and 29 American stations; but the residual quantity on the side of the supposed cooling power of the solar spots, (scarcely 0°·42 Centigrade, or less than 0°·8 Fahrenheit), is so small, that even for the particular localities it may be attributed to errors of observation or to the influence of the direction of the wind. We remark in this comparison indications of the opposite affections of the two sides of the Atlantic, in accordance with Dove's general inferences.

It still remains to speak of the third and outermost of the three solar envelopes which have been referred to; it is supposed to be above the photosphere, and to be cloudy and of imperfect transparency. The remarkable phenomena of red mountain- or flame-like forms, which, during the total solar eclipse of the 8th of July, 1842, were seen, though not for the first time yet much more clearly than before, and observed simultaneously by several of the most practised observers, have led to the hypothesis or assumption of such a third envelope or covering. Arago, with great acumen, and after a thorough examination of the observations, has enumerated in a treatise on the subject ([476]), the grounds which appear to necessitate this assumption. He has at the same time shewn that similar rose-coloured marginal protuberances have been already described on occasions of total or annular eclipses of the sun since 1706 ([477]). On the recent occasion, July 8, 1842, when the disk of the

Moon covered the entire solar disk, (its apparent diameter being at that time greater than that of the Sun,) there was seen not only a (478) white shining appearance forming a corona or bright circle surrounding the Moon, but also, as if attached in the limb or margin of the Moon, two or three rose-tinted elevations, which some observers compared to mountains, others to reddened masses of ice, and others to motionless jagged or pointed flames. Arago, Laugier, and Mauvais at Perpignan, Petit at Montpellier, Airy on the Superga near Turin, Schumacher at Vienna, and many other astronomers, agreed perfectly with each other in respect to the main features of the general phenomenon, notwithstanding the great diversity of the telescopes employed. The elevations were not seen in all cases at the same moment of absolute time, and at some places they were even observed with the naked eye. Their heights were also differently estimated by the different observers: the surest estimation is probably that of Petit, the director of the Observatory at Toulouse: it was 1′ 45″, which, if the protuberances were really solar mountains, would correspond to elevations of 40,000 geographical miles: this is almost seven times the diameter of our globe, while the solar diameter is only 112 times that diameter. The consideration of the whole of these phenomena has led to the very probable hypothesis of these roseate forms being undulations or protuberances of the third envelope, or masses of cloud illuminated and coloured by the photosphere (479). Arago, in putting forward this hypothesis, expresses at the same time the conjecture, that the darkness of the deep blue sky at great terrestrial altitudes, the intensity of which I had myself measured on the highest Cordilleras,—(instrumental means for such measurements

were indeed, and even still are, very imperfect,)—may render it possible to obtain frequent observations of those mountain-like clouds belonging to the outermost vaporous solar atmosphere (480).

It is only at two periods of the year, viz. on the 8th of June and 9th of December, that the solar spots describe on the Sun's disk neither convex nor concave curves, but straight lines parallel to each other and to the solar equator; and if we examine the zones in which the spots are most frequent, we find as a characteristic circumstance that they are rarely seen in the equatorial zone itself, from about 3° North to 3° South latitude, and that they are entirely wanting in the neighbourhood of the poles. They are on the whole most abundant in a belt between 11° and 15° north of the equator, and generally more frequent in the northern than in the southern hemisphere; or, as Sömmering thinks, are to be seen farther from the equator in the northern than in the southern hemisphere. (Herschel, Outlines, § 393; Cape Observations, p. 433.) Galileo had already assigned 29° of north and south heliocentric latitude for the extreme limits of the spots. Sir John Herschel has extended these limits to 35°; as has also Schwabe. (Schum. Astr. Nachr., No. 473.) Single spots have been found by Laugier (Comptes Rendus, T. xv. p. 944), as far as 41°, and by Schwabe even as far as 50°. A spot described by La Hire in 70° North latitude must be regarded as a phenomenon of most rare occurrence.

The above described distribution of the spots on the Sun's disk, their rarity on the equator itself and in the polar regions, and their arrangement parallel to the equator, have given occasion to Sir John Herschel to conjecture that obstacles

which the third, or outermost, vaporous envelope may oppose at some points to the escape of heat, may give rise in the solar atmosphere to currents from the poles to the equator, similar to those which, from the different velocity of rotation under different parallels of latitude, cause on our globe the trade-winds and the calms which prevail in the more immediate vicinity of the equator. Particular spots are sometimes so permanent as to return continually for six entire months, as the large spot of 1779. Schwabe was able to trace the same group eight times in the year 1840. A black nucleus which is figured in the Cape Observations of Sir John Herschel, (of which I have so extensively availed myself), was found by exact measurement to be of such magnitude, that if our entire earth had been thrown into the opening in the photosphere, there would still have remained on either side a vacant space of more than 920 geographical miles. Sömmering calls attention to the circumstance that there are certain meridians or bands of longitude in which during many years he never saw a solar spot. (Thilo de Solis maculis a Sœmmeringio observatis, 1828, p. 22.) The very different periods of rotation which have been assigned to the Sun are not by any means to be attributed solely to inaccuracy of observation; they proceed from the circumstance that some spots change their places upon the Sun's disk. Laugier has devoted a particular examination to this subject, and has observed spots from which rotations of 24·28 and 26·46 days might be severally derived. Our knowledge of the actual time of the Sun's rotation can, therefore, only be affirmed to correspond to the mean result derived from a great number of observed spots, which by the permanence of their form and the in-

variability of their distances from other spots visible at the same time, afford an apparently satisfactory degree of security.

Although solar spots may much oftener than is generally supposed be distinctly recognised by the unassisted eye of an observer looking for them, yet after careful investigation we find, between the beginning of the 9th and of the 17th centuries, at the utmost, not more than two or three notices of their appearance upon which we can depend. I reckon as such the supposed presence of Mercury upon the sun's disk for a period of eight days, in the year 807, recorded in the annals of the kings of the Franks, which were ascribed first to an astronomer belonging to the Benedictine order, and afterwards to Eginhard; the transit of Venus over the Sun, lasting 91 days, said to be observed under the Caliph Al Motassem in 840; and the "Signa in Sole" in the year 1096, according to the Staindelii Chronicon. The historical records of occasions on which the Sun has been darkened,—or, as it would be more accurately expressed, when there has been during a longer or shorter time a diminution of the light of day,—have induced me for a long time past to institute particular inquiries into such meteorological, or possibly cosmical, phenomena ([481]). As extensive series of solar spots (those observed by Hevelius on the 20th of July, 1643, covered a third part of the Sun's disk) are always accompanied by numerous *faculæ,* I am but little inclined to ascribe to their occurrence obscurations during which stars were sometimes visible as in total eclipses of the Sun.

The diminutions of daylight related by annalists may, I think, be classed under three heads according to three wholly

different causes to which they may by possibility be due. Total eclipses of the Sun are excluded, were it only from the recorded continuance of the obscurations for several hours,—whereas, according to Du Sejours' calculation, the longest possible duration of a total solar eclipse is 7′ 58″ at the equator, and in the latitude of Paris only 6′ 10″). The three causes to which I allude are: 1, disturbances in the process by which light is evolved, or a less intensity in the photosphere; 2, impediments to the radiation of solar light and heat arising in the external opaque vaporous veil or covering surrounding the photosphere, by the formation in it of unusually large and dense clouds; 3, extraneous admixtures in our own atmosphere chiefly of an organic character, as "trade wind dust," "inky rain," or the Chinese "sand-rain," described by Macgowan as lasting several days. The causes mentioned under heads 2 and 3 require no enfeeblement of the (perhaps) electro-magnetic, luminous process in the Sun's atmosphere, (a perpetual Aurora or polar light) ([482]); the third is open to the objection that it is opposed to the visibility of stars in the middle of the day, which is so often spoken of in the too scanty descriptions given of the circumstances accompanying these mysterious phenomena.

Arago's discovery of chromatic polarisation has tended not only to strengthen the belief of a third and outermost covering of the Sun, but also to confirm the conjectures which have been formed respecting the physical constitution of the central body of our planetary system. "A ray of light arriving at our eyes from the remotest regions of space tells us in the polariscope, as it were of itself, whether it is

reflected or refracted, whether it emanates from a solid, from a liquid, or from a gaseous body, and even announces its degree of intensity." (Kosmos, Bd. i. S. 35, Bd. ii. S. 370; English Ed., Vol. i. p. 37, and Vol. ii. p. 329.) It is essential to distinguish between natural light as it proceeds directly from the sun, the fixed stars, or gas-flames, and is polarized by reflection from a glass plate under an angle of 35° 25′,—and the polarized light which radiates spontaneously as such from certain substances (glowing solids as well as liquids). The polarised light given out by the last-mentioned class of bodies proceeds very probably from their interior; on passing from a denser body into the thinner surrounding atmospheric strata, it is refracted at the surface, and a part of the refracted ray returns inwards and becomes polarized *by reflection*, while the other portion presents the properties of light polarised *by refraction*. The chromatic polariscope distinguishes between these two kinds of light by the opposite position of the coloured complementary images. Arago has shewn by careful experiments extending back to before 1820, that radiant solid bodies,—*e. g.*, a red-hot iron ball, or glowing, shining, molten metal in a liquid state,—give out simply natural light in the rays which issue from them in a perpendicular direction, whereas the luminous rays which arrive at our eyes under very small angles from their edges are polarized. If we now turn the polariscope, by which these two kinds of light are distinguished from each other, to gas-flames, no polarisation is discovered, however small may be the angles at which the rays emanate. Although light may be produced in the interior of the gaseous body, yet, in

the small degree of density of gaseous strata, the longer path traversed by the very oblique rays does not appear to lessen their number and strength; nor does the transition to another medium on issuing forth at the surface appear to produce polarisation by refraction. Now as the Sun's light coming from its margin in a very oblique direction, and at very small angles, also shews no trace of polarisation when examined by the polariscope, it follows from this important comparison that the Sun's brightness does not proceed from its solid body nor from any liquid substance, but from a gaseous self-luminous envelope. We have here a highly important physical analysis of the photosphere.

The polariscope has also led to the conclusion that the Sun's light is not greater at the centre of the disk than at the edges. If the two complementary coloured images of the Sun, the red and the blue, are so placed over each other that the margin of the one image coincides with the centre of the other, a perfect white is produced. If the intensity of light in the different parts of the solar disk were not the same,—if, for example, the centre of the sun were more luminous than the limb,—then in the partial superposition of the images the conjoined segments of the blue and red disks would appear not of a pure white but of a pale red, because the blue rays would only be able to neutralize a portion of the more abundant red rays. Remembering, then, that in the gaseous photosphere of the Sun, quite in opposition to what takes place in solid or liquid bodies, the smallness of the angles at which the luminous rays come to us from the edges of the Sun's disk does not lessen their number, while the same visual angle comprehends a greater

number of luminous points at the margin than at the centre, we see that we cannot reckon on the compensation which, if the Sun were a solid body, as a glowing iron ball, would take place at the edges, between the effects of smallness of radiation-angle, and the comprehension of a greater number of luminous points within the same angle of vision. If, then, there were no additional circumstance to be taken into account, it would follow that the gaseous self-luminous envelope, *i. e.* the solar disk seen by us, should, in contradiction to the indications of the polariscope, which show equal intensity of light in the centre and at the limb, be brighter at the edges than at the centre. That this is not so must be attributed to the outermost opaque or imperfectly transparent vaporous envelope or veil which surrounds the photosphere, and dims the light from the centre less than the rays from the margins which traverse the envelope by a longer path ([483]). Bouguer and Laplace, Airy, and Sir John Herschel, are opposed to the views taken by Arago: they hold the intensity of the light of the edges to be less than that of the centre, and the last-named of these distinguished physicists and astronomers remarks ([484]), "granting the existence of such an atmosphere" (or external vaporous envelope) "its form in obedience to the laws of equilibrium must be that of an oblate spheroid, the ellipticities of whose strata differ from each other and from that of the nucleus. Consequently the equatorial portions of this envelope must be of a thickness different from that of the polar, density for density, so that a different obstacle must be thereby opposed to the escape of heat from the equatorial and polar regions of the Sun." Arago is at the present moment occupied with experiments,

designed not only for testing his own views, but also for reducing the results of observation to exact numerical proportions.

The comparison of the Sun's light with the two most intense artificial lights which have yet been produced, gives (according to the still very imperfect state of photometry) the following numerical results. In the ingenious experiments by Fizeau and Foucault, Drummond's light (produced by the flame of an oxy-hydrogen lamp directed upon lime) is to the light from the Sun's disk as 1 to 146. The intensity of the light produced between two charcoal points by a Bunsen's pile in Davy's experiment, with a battery of 46 small plates, was to the solar light as 1 : 4·2, and with large plates as 1 : 2·5, or more than one-third of the Sun's light ([485]). If we still hear with astonishment that Drummond's dazzling light appears as a black spot when projected on the Sun's disk, we may regard with the higher admiration the genius of Galileo, in drawing, in 1612, from a series of inferences respecting the smallness of the distance from the Sun at which Venus would cease to be visible to the naked eye, the conclusion, that the blackest nucleus of a solar spot is brighter than the brightest part of the full moon ([486]).

Taking the intensity of the whole light of the Sun as equal to 1000, William Herschel estimated that of the penumbras on the average as 469, and that of the black nuclei themselves as 7. According to this assumption, which of course can only be regarded as a very conjectural one, and taking with Bouguer the light of the Sun to be 300000 times as strong as that of the full moon, a black nucleus would still possess 2000 times more light than the full

moon. The degree of illumination of the nuclei of the solar spots as seen by us,—(*i. e.* of the dark body of the Sun illuminated by reflection from the sides of the opening in the photosphere and from the inner vaporous envelope which produces the penumbras, and by the light of the terrestrial atmospheric strata through which we look),—has been shown in a very remarkable manner by some observations made during transits of Mercury. Compared with the Planet, whose dark nocturnal, or unilluminated side is then turned towards the earth, the darkest nuclei of spots in its vicinity appeared of a light brownish grey ([487]). An excellent observer, Hofrath Schwabe, of Dessau, had his attention particularly drawn to this difference between the darkness of the planet and of the nuclei of the solar spots, on the occasion of the transit of Mercury on the 5th of May, 1832. When observing in Peru the transit of the same planet, which took place on the 9th of November, 1802, I unfortunately was so much occupied with noticing the distances from the wires, that the comparison of the disk with dark solar spots which it almost touched, escaped me. That the spots radiate sensibly less heat than the other portions of the Sun's disk, was shown as early as 1815, by Professor Henry, of Princeton in the United States, by means of very delicate experiments, in which the image of the Sun and that of a large spot were projected on a screen, and the difference of temperature was measured by a thermo-electric apparatus ([488]).

Whether the calorific are distinguished from the luminous rays by different lengths in the transverse undulations of the ether,—or whether they are identical with the luminous rays, but only excite in our organs the sensation of light at a

certain rapidity of vibrations which produces very high temperatures,—in either case the Sun, as the chief source of light and heat, may elicit and animate magnetic forces on our planet, and especially in its gaseous envelope, the atmosphere. The early knowledge of thermo-electric phenomena in crystallised bodies (tourmaline, boracite, and topaz), and Oersted's great discovery in 1820, according to which every conductor of electricity exerts, during the time that the electric current is passing through it, a determinate action upon a magnetic needle, gave practical manifestation of the intimate relations subsisting between heat, electricity, and mgnetism. The ingenious Ampère, who ascribed all magnetism to electric currents situated in a plane perpendicular to the axes of the magnets, based on the idea of this relationship between heat, electricity, and magnetism the hypothesis, that terrestrial magnetism, (*i. e.* the magnetic charge of the Earth), is produced by electric currents passing round the planets from east to west, and that the solar heat being the exciter of these currents, the diurnal variation of the magnetic declination is the result of the change of temperature produced by the diurnal change in the Sun's altitude. The thermo-electric experiments of Seebeck, in which differences of temperature in the points of connection of a circle, made of bismuth and copper, or other dissimilar metals, cause a deflection of the magnetic needle, supported Ampère's views.

A new and brilliant discovery of Faraday's, the following out of which by the author is taking place almost simultaneously with the printing of these pages, throws an unexpected light on this important subject. Whereas earlier investigations

of this great physicist had made it appear that all gases are diamagnetic—*i. e.* that they arrange themselves east and west like bismuth and phosphorus (oxygen gas, however, the most feebly so),—his last train of researches, the commencement of which goes back to 1847, shews that oxygen, unlike all other gases in this respect, comports itself like iron in taking a north and south axial direction; and farther, that it loses part of its paramagnetic force by rarefaction and increase of temperature. As the diamagnetic quality of the other constituents of the atmosphere—nitrogen and carbonic acid gas—is not modified by expansion or by increase of temperature, we have only to consider the atmosphere of oxygen, which surrounds the Earth like a dome of thin sheet iron and receives magnetism from it. The half of the dome which is turned towards the sun becomes less paramagnetic than the opposite one, and, as by the Earth's rotation and revolution roumd the Sun, the boundaries between these two half domes are continually shifting their place, Faraday is inclined to derive a part of the variations of magnetism on the surface of our globe, from these thermic relations. The assimilation, by adequate experimental research, of one kind of gas, oxygen, to iron, is an important discovery of the time in which we live (489), and is of the higher importance, because it is probable that oxygen constitutes almost the half of all the ponderable matter belonging to the accessible portions of our planet. Without the assumption of magnetic poles in the sun, or of proper magnetic forces in the solar rays, the central body of our system may excite magnetic activity on our planet simply by its powerful agency as a source of heat.

The attempts which have been made to show, by meteo-

rological observations continued for several years at single stations, that one side of the sun (*ex. gr.* the side which was turned towards the earth on the 1st of January, 1846) has a stronger heating power than the opposite side ([490]), have, like the so-called proofs of the decrease of the sun's diameter deduced from the earlier Greenwich Observations of Maskelyne, led to no certain result. The periodicity of the solar spots, reduced to definite numerical ratios by Hofrath Schwabe, of Dessau, appears to rest on a better foundation. Among the astronomers now living who are provided with excellent instruments, no other one has been able to devote to this subject such persevering attention as Schwabe has done. During the long space of twenty-four years he has often examined the sun's disk for upwards of 300 days in each year. His observations of the solar spots from 1844 to 1850 not being yet published, I have been indebted to his friendship for the opportunity of consulting them, and at the same time for answers to many questions which I proposed to him. I close the present section, on the physical constitution of the central body of our system, with the results with which his kindness has enriched the astronomical portion of my work:—

"The numbers contained in the following table leave no room to doubt that, at least from the year 1826 to 1850, the solar spots have shown a period of about ten years, with maxima in 1828, 1837, and 1848, and minima in 1833 and 1843. I have had no opportunity of becoming acquainted with any continuous series of earlier observations, but I readily admit that the period may be a variable one ([491]):—

| Year. | Groups. | Days free from Spots. | Days of Observation. |
|---|---|---|---|
| 1826 | 118 | 22 | 277 |
| 1827 | 161 | 2 | 273 |
| 1828 | 225 | 0 | 282 |
| 1829 | 199 | 0 | 244 |
| 1830 | 190 | 1 | 217 |
| 1831 | 149 | 3 | 239 |
| 1832 | 84 | 49 | 270 |
| 1833 | 33 | 139 | 267 |
| 1834 | 51 | 120 | 273 |
| 1835 | 173 | 18 | 244 |
| 1836 | 272 | 0 | 200 |
| 1837 | 333 | 0 | 168 |
| 1838 | 282 | 0 | 202 |
| 1839 | 162 | 0 | 205 |
| 1840 | 152 | 3 | 263 |
| 1841 | 102 | 15 | 283 |
| 1842 | 68 | 64 | 307 |
| 1843 | 34 | 149 | 312 |
| 1844 | 52 | 111 | 321 |
| 1845 | 114 | 29 | 332 |
| 1846 | 157 | 1 | 314 |
| 1847 | 257 | 0 | 276 |
| 1848 | 330 | 0 | 278 |
| 1849 | 238 | 0 | 285 |
| 1850 | 186 | 2 | 308 |

"In almost all the years except those of the minima I observed large spots visible to the naked eye—I mean spots whose diameters are above 50″, which is the size at which they begin to be discernible by a keen-sighted unassisted eye. The largest spots appeared in the years

1828, 1829, 1831, 1836, 1837, 1838, 1839, 1847, and 1848.

"The spots are undoubtedly in close relation to the formation of faculæ. I have seen abundant instances of the disappearance of spots being followed by the appearance in the same places of faculæ and 'Narben' (scars, cicatrices), and also of new spots showing themselves in the faculæ. Each spot is surrounded by more or less intensely luminous cloud. I do not believe that the spots on the sun have any influence on the temperature of the year. I record the indications of the barometer and thermometer three times a day, but as yet the means deduced therefrom have not suggested any sensible connection between climatic conditions and the number of spots. Even if single cases were to show such an apparent connection, it still would not deserve to have any importance attached to it, until confirmed by temperature results from many other parts of the Earth. If the solar spots should really have any minute influence on our atmosphere, my table would perhaps rather seem to indicate that the years when the spots were most numerous had fewer clear days than those in which spots were less frequent (Schwabe in Schum. Astron. Nachr., No. 638, S. 221).

"William Herschel gave the name of *faculæ* to the brighter luminous streaks which show themselves only towards the margin, and that of *Narben* to the veins or streaks which are only seen towards the middle of the sun's disk (Astron. Nachr., No. 350, S. 243). I think I have convinced myself that 'Faculæ' and 'Narben' proceed from the same condensed luminous cloud, which at the margin of the sun's disk stands out brighter, but in the middle of

the disk appears in the form of Narben, or less bright than the general surface. I prefer calling all brighter places on the sun's disk "luminous cloud," dividing them according to their forms into masses and streaks. This luminous cloud is distributed irregularly over the sun's surface, and sometimes, when it shows itself most prominently, even gives to the solar disk a *marbled* appearance. It is often distinctly visible on the whole of the sun's margin, sometimes even up to the poles; but it always appears most strongly in the two zones which the spots more particularly affect, and this even at times when there are no spots there. On such occasions these two bright zones of the sun's disk remind one vividly of Jupiter's belts.

"Ridges are the less bright parts intervening between the streaks of bright cloud, and showing always a shagreen-like aspect, reminding one of sand in which all the grains are alike in size. On this shagreen-like surface we sometimes see extraordinarily small, faint, grey (not black) points (pores), which are again traversed by exceedingly fine, dark, small veins (Astr. Nachr., No. 473, S. 286). Such pores, when in masses, form grey cloud-like spaces, and even the penumbras of the solar spots. In these latter we see pores and black points extend, mostly in radiating lines, from the nucleus to the circumference of the penumbra; and hence arises the frequent agreement in form between the nucleus and the penumbra."

The explanation and connection of these varying phenomena will perhaps first become known in their full importance to the investigators of nature, when, at some future day, and under the long-continued serenity of a tropical sky during an interval of several months, there shall be ob-

tained, by the help of photographic apparatus, combined with mechanical clockwork movement, an uninterrupted series of graphical representations of solar spots (492). Meteorological processes taking place in the gaseous envelopes of the dark solar body cause the phenomena which we term solar spots and condensed luminous clouds. There, as well as in the meteorology of our own planet, the disturbances are probably so varied and complicated in their kind, and so intricate in respect to the causes in which they originate, and which are partly general and partly local, that it is only by long-continued observation, aiming at the greatest attainable completeness, that we can hope to resolve even a portion of the still obscure problems which they present.

# II.

## The Planets.

Before we enter into descriptions of each of these bodies viewed individually, I propose to present some general and comparative considerations respecting the entire class to which they belong. These considerations will embrace, in conformity to the state of discovery at the present moment, 22 primary planets, and 21 subordinate bodies, moons or satellites. They do not apply to other classes of bodies in our planetary or solar system, among which comets whose orbits have been calculated are already ten times as numerous. Planets have, generally speaking, only a slight degree of scintillation, because they shine by the solar light reflected from their disks. (The difference in this respect between disks and luminous points has been explained in pp. 68 and xxviii. of the First Part of the present volume.) In the pale radiance of the illuminated moon, and in the reddened light of its darkened disk, which shows itself with peculiar strength within the tropics, the solar light, as seen by the observer stationed on the Earth, has suffered a two-fold change of direction. That the Earth and other planets are

capable of evolving a faint light of their own, not derived from reflection,—as is sometimes evidenced by remarkable phenomena appearing in the part of Venus which is not turned towards the sun,—has been already remarked in the first volume of the present work ([493]).

We propose to consider the planets in regard to their number, the order of succession of their discovery, their volume as compared with each other and with their distances from the sun, and according to their relative densities, masses, times of rotation, excentricities and inclinations of axis, as well as to the characteristic diversity of those within and those beyond the zone of the small planets. Among these subjects of comparative consideration I have, in accordance with the nature of my work, devoted particular care to the selection of the most accurate numerical data for the epoch at which these pages are printed—*i. e.*, the results of what are supposed to be the best assured as well as the most recent investigations.

## *a. Primary Planets.*

1. *Number and epoch of discovery.*—Of the seven cosmical bodies which, by their continually varying relative positions and distances apart, have ever since the remotest antiquity been distinguished from the "unwandering orbs" of the heaven of the fixed stars, which to all sensible appearance preserve their relative positions and distances unchanged, five only—Mercury, Venus, Mars, Jupiter, and Saturn—wear the appearance of stars: "quinque *stellas* errantes;" while the sun and moon, from the size of their disks, their importance to man, and the place assigned to

them in mythological systems ([494]), were classed apart. Thus, according to Diodorus (ii. 30), the Chaldeans recognised only five planets; Plato, also, in the Timæus, on the only occasion on which he refers to the planets, says expressly—"Around the Earth reposing in the centre of the Cosmos move in seven orbits the moon, the sun, and five other stars to which the name of planets has been attached" ([495]). So, also, in the ancient Pythagorean representation of the structure of the heavens, according to Philolaus, among the ten divine bodies or celestial orbs which circle round the central fire (the hearth of the Universe, εστια), the five planets (which are named) ([496]) revolve immediately below the heaven of the fixed stars; then follow the sun, moon, earth, and ἀντιχθων (anti-earth). Ptolemy himself still continues to speak of five planets only. The enumeration of the series of seven planets as distributed by Julius Firmicus ([497]) among the Decans, as represented in the zodiac of Bianchini (examined by me elsewhere ([498]), and probably belonging to the third century of our era), and as contained in Egyptian monuments of the times of the Cæsars, belongs not to ancient astronomy, but to later periods, when astrological fancies had become everywhere prevalent ([499]). That the moon should have been included in the series of the seven planets need not surprise us, since, with the exception of a remarkable view of attraction taken by Anaxagoras (Kosmos, Bd. ii. S. 348 and 501, Anm. 27; Eng. edit. p. 308, and Note 467), its more immediate dependence on the Earth is scarcely ever alluded to by the ancients. On the other hand, in a notice of the supposed structure of the universe mentioned by Vitruvius ([500]), and by Martianus Capella ([501]), but without naming its author,

the two planets which we call inferior planets, Mercury and Venus, are regarded as satellites of the sun, which is itself supposed to revolve round the Earth. There is as little reason for terming such a system an Egyptian one ([502]) as for confounding it with Ptolemy's epicycles, or Tycho Brahe's view of the universe.

The names by which the five star-like planets were designated by the nations of antiquity are of two kinds—mythological or names of divinities,—and significant or descriptive, taken from real or supposed physical properties. It is the more difficult to determine, from the only sources of information hitherto open to us, what may have been derived in this respect originally from the Egyptians, and what from the Chaldeans, because Greek writers have handed down to us not the original names themselves as they were in use among other nations, but only Greek equivalents, which they modified according to their own particular views. What knowledge was possessed by the Egyptians before the Chaldeans, and whether the latter are to be regarded merely as the highly-gifted scholars of the former ([503]), are questions which touch on the important but obscure problems of the earliest civilization of the human race, and the beginning of scientific development of thought on the banks of the Nile, or on those of the Euphrates. Although the Egyptian denominations of the 36 Decans are known, only one or two of the Egyptian names of the planets have come down to us ([504]).

It is remarkable that the mythological names of the planets, which are also given by Diodorus, are the only ones used by Plato and Aristotle; whereas later, for example in the book "de Mundo," falsely ascribed to Aristotle, we find both kinds of appellations—the mythological and the

descriptive or expressive—intermixed; φαινων for Saturn, στιλβων for Mercury, and πυρόεις for Mars ([505]). If, as we learn from passages in the Commentary of Simplicius (p. 122) to Aristotle's 8th book "de Cœlo," and from Hyginus, Diodorus, and Theon of Smyrna, Saturn, the outermost of all the planets then known, received, singularly enough, the title of Sun, it can only have been because its position and the length of its revolution were supposed to raise it to the rank of ruler over the other planets. Descriptive appellations, however ancient some of them may have been, and probably the same as were used by the Chaldeans, are yet first found in frequent use among Greek and Roman writers in the time of the Cæsars. Their prevalence was connected with the influence of astrology. The planetary signs, with the exception of a round disk for the sun, and the crescent or sickle for the moon, on Egyptian monuments, are of very late origin; according to Letronne's researches, they even do not go back beyond the tenth century ([506]). They are even not found upon stones having gnostic inscriptions. Later copyists have introduced them into gnostic and alchemistic manuscripts; but they are hardly ever found in the oldest manuscripts which we possess of the Greek astronomers, Ptolemy, Theon, or Cleomedes. The earliest planetary signs, some of which (those for Jupiter and Mars) have been derived, as Salmasius has observed with his wonted sagacity, from alphabetical characters, were very different from those which we now employ, the particular forms of which are little, if at all, older than the 15th century. It is undoubted, and is proved by a passage borrowed by Olimpiodorus from Proclus (ad Tim. ed. Basil. p. 14), as well as by a late scholion to Pindar (Isthm. V. 2), that the symbolising custom of dedicating certain metals to

the different planets belonged already to the Neo-platonic Alexandrine representations of the 5th century. (Compare Olympiod. Comment. in Aristot. Meteorol. cap. 7, 3 in Ideler's edition of the Meteor. T. ii. p. 163; also T. i. pp. 199 and 251).

Although the number of visible planets known to the ancients amounted, according to the first limitation of the term, only to five, and subsequently, when the larger discs of the Sun and Moon were added, to seven; yet it was already conjectured that besides these visible planets there existed others, unseen because possessing only a fainter degree of lustre. This opinion is pointed out by Simplicius as an Aristotelian one: "It may be that lunar eclipses are sometimes caused by such dark bodies moving round the common centre as well as by the Earth." Artemidorus of Ephesus, whom Strabo often refers to as a geographer, believed in the existence of a countless number of such dark revolving cosmical bodies. The old imaginary anti-earth (ἀντιχθων) of the Pythagoreans does not belong to the sphere of these conjectures. It and the Earth were supposed to have a parallel concentric movement; it was an idea devised to spare the Earth, which was supposed to perform around the central fire a planetary revolution in 24 hours, from having also to execute a movement of rotation, and, indeed, represented no doubt the opposite hemisphere, or the antipodal half of our planet ([507]).

If from the entire number of planetary bodies now known to us, 43 primary planets and satellites, being six times as many as were known to the ancients, we take the 36 which have been discovered since the invention of the telescope, and divide them chronologically according to the periods of

their discovery, we find that *nine* were first seen in the 17th century, *nine* again in the 18th, and *eighteen* in the first half of the present or 19th century.

*Chronological table of planetary discoveries, or of primary planets and satellites, since the invention of the telescope, in* 1608 *:—*

A. The Seventeenth Century.

Four satellites of Jupiter: by Simon Marius, at Ansbach, Dec. 29, 1609; and by Galileo, at Padua, Jan. 7, 1610.

Compound form of Saturn: Galileo, Nov. 1610; the two side anses seen by Hevelius, 1656; final recognition of the true form of the ring by Huygens, Dec. 17, 1657.

The 6th satellite of Saturn (Titan): Huygens, March 25, 1655.

The 8th satellite of Saturn (the outermost one, Japetus): Domin. Cassini, Oct. 1671.

The 5th satellite of Saturn (Rhea): Cassini, Dec. 23, 1672.

The 3d and 4th satellites of Saturn (Tethys and Dione): Cassini, end of March 1684.

B. Eighteenth Century.

Uranus: William Herschel, March 13, 1781, at Bath.

The 2d and 4th satellites of Uranus: William Herschel, Jan. 11, 1787.

The 1st satellite of Saturn (Mimas): W. Herschel, Aug. 28, 1789.

The 2d satellite of Saturn (Enceladus): W. Herschel, Sept. 17, 1789.

The 1st satellite of Uranus: W. Herschel, Jan. 18 1790.

The 5th satellite of Uranus: W. Herschel, Feb. 9, 1790.

The 6th satellite of Uranus: W. Herschel, Feb. 28, 1794.

The 3d satellite of Uranus: W. Herschel, March 26, 1794.

C. Nineteenth Century.

CERES*: Piazzi, at Palermo, Jan. 1, 1801.

PALLAS*: Olbers, at Bremen, March 28, 1802.

JUNO*: Harding, at Lilienthal, Sept. 1, 1804.

VESTA*: Olbers, at Bremen, March 29, 1807.

(An interval of 38 years occurred without any planetary discovery.)

ASTRÆA*: Hencke, at Driesen, Dec. 8, 1845.

NEPTUNE: Galle, at Berlin, Sept. 23, 1846.

The 1st satellite of Neptune: W. Lassell, at Starfield, near Liverpool, Nov. 1846; Bond, at Cambridge, U.S.

HEBE*: Hencke, at Driesen, July 1, 1847.

IRIS*: Hind, London, Aug. 13, 1847.

FLORA*: Hind, London, Oct. 18, 1847.

METIS*: Graham, at Markree Castle, April 25, 1848.

The 7th satellite of Saturn (Hyperion): Bond, at Cambridge, U.S., 16-19th Sept. 1848; Lassell, at Liverpool, 19-20th Sept. 1848.

HYGEIA*: De Gasparis, at Naples, April 12, 1849.

PARTHENOPE*: De Gasparis, at Naples, May 11, 1850.

The second satellite of Neptune: Lassell, at Liverpool, August 14, 1850.

VICTORIA*: Hind, London, Sept. 13, 1850.

EGERIA*: De Gasparis, at Naples, Nov. 2, 1850.

IRENE*: Hind, London, May 19, 1851; and De Gasparis, at Naples, May 23, 1851.

In the above chronological review, (508) the primary planets are distinguished from the secondary planets or satellites by a difference of type. An asterisk has been appended to each member of that class of primary planets which form a peculiar and very extended group, as it were a ring of 132 millions of geographical miles in breadth, situated between Mars and Jupiter, and are commonly called the smaller planets, and sometimes telescopic planets, co-planets, asteroids or planetoids. Of these, 4 were discovered in the first seven years of the present century, and 10 in the course of the six years which have just terminated —a result due less to the improvement which has taken place in telescopes, than to the diligence and skill of observers, and in particular to the improved star maps, which have been so greatly enriched by the addition of stars of the 9th and 10th magnitudes. Moving points are now more easily distinguished from among the adjacent unmoving or fixed stars (See First Part of the present volume, p. 98-99; and in the original German, S. 155). The number of the primary planets has been exactly doubled since the publication of the first volume of Kosmos (509), so quickly have discoveries succeeded each other, so rapid has been the advance in the extension and completion of the topography of our planetary system.

2. *Distribution of planets into two groups.*—If, in the solar domain, we regard the region of the small planets situated between the orbits of Mars and Jupiter, but nearer on the whole to the former than to the latter, as a *dividing*

zone in space, or as forming, as it were, a *middle* group; then, as has been already remarked, the *inner* planets—those which are nearer to the Sun—viz. Mercury, Venus, Earth, and Mars—present many points of resemblance to each other and of contrast to the *outer* planets—Jupiter, Saturn, Uranus, and Neptune—situated further from the Sun, beyond the dividing zone. The middle group of the three, or that of the small planets, scarcely occupies half the interval between the orbits of Mars and of Jupiter. In the space between these two greater planets it is the part nearest to Mars which, so far as our present knowledge enables us to judge, is most richly furnished; for if, in the zone of the asteroids, we consider the extreme ones on either side—Flora and Hygeia—we find that Jupiter is more than three times farther from Hygeia than Flora is from Mars. This middle group is strongly distinguished from the others by the intersecting, highly inclined, and excentric orbits, and by the very small dimensions of the planets of which it consists. The inclination of the orbits to the ecliptic rises in Juno to 13° 3′, in Hebe to 14° 47′, in Egeria to 16° 33′, and in Pallas even to 34° 37′; while in this same middle group it falls as low as 5° 19′ in Astrea, 4° 37′ in Parthenope, and even as 3° 47′ in Hygeia. The small planets whose orbits have less than 7° of inclination are, in descending order, Flora, Metis, Iris, Astræa, Parthenope, and Hygeia; but in none of these are the inclinations as small as in Venus, Saturn, Mars, Neptune, Jupiter, and Uranus. In excentricity of orbit some of the small planets exceed and some fall short of Mercury (0.206), Juno, Pallas, Iris, and Victoria having 0.255, 0.239, 0.232, and 0,218; while Ceres, Egeria, and Vesta, have respectively

0.076, 0.086, 0.089, being excentricities inferior to that of the orbit of Mars (0,093), but without making so near an approach to a circular orbit as the planets Jupiter, Saturn, and Uranus. The diameters of the telescopic planets are so small as to render their measurement very difficult and uncertain. From the observations of Lamont at Munich, and of Mädler with the Dorpat refractor, it is probable that the largest of them all does not exceed at the utmost 145 German, or 580 English geographical miles, being $\frac{1}{5}$th of the diameter of Mercury, and $\frac{1}{12}$th of that of the Earth.

If we call the four planets nearest to the Sun, between the ring of Asteroids or small planets and the central body, *inner* planets, and the four planets which are furthest from the sun (being placed between the ring of the asteroids and the unknown extremities of the solar domain) *outer* planets, we find the inner planets all of moderate magnitude, comparatively dense, slow in their movements of rotation round their axes, (the periods being nearly similar in all, differing little in any case from 24 hours), and, with the exception of the Earth, wholly destitute of satellites. The four *outer* planets,—Jupiter, Saturn, Uranus, and Neptune,—on the other hand, are much larger, five times less dense, rotate twice as rapidly round their axes, are more flattened at the poles, and richer in satellites in the average proportion of 20 to 1. Of the four inner planets the Earth is the largest (the diameters of Mercury and Mars are respectively $\frac{2}{5}$ths and $\frac{1}{2}$ of the Earth's diameter); while the outer planets, on the other hand, are from 4·2 to 11·2 times larger than the Earth. The density of the Earth being taken as unity, the densities of Venus and Mars agree with it to less than $\frac{1}{10}$th, and the density

of Mercury (according to the mass of that planet as determined by Encke) is only a little greater. On the other hand, none of the outer planets exceed $\frac{1}{4}$ in density; Saturn is even only $\frac{1}{7}$th, being little more than half as dense as the other outer planets and the sun. The outer planets present to us a phenomenon unique in the entire solar system—*i. e.*, the wondrous appearance of a solid ring encircling its primary planet, but detached from it and suspended freely in space. They also present to us atmospheres which, by the peculiarities of the condensations taking place in them, appear to our eyes as variable, and in Saturn sometimes even as interrupted, streaks or belts.

Although, in the important division of the planets into two groups of interior and exterior planets, the facts of absolute magnitude, density, compression at the poles, velocity of rotation, and presence or absence of moons or satellites, show a general connection with the solar distances, or with the semi-major axes of the orbits, yet this connection or dependence can by no means be asserted in respect to each individual member of these groups. As I have already before remarked, we as yet know of no inherent necessity, no mechanical natural law, which—as the fine law which links together the squares of the times of revolution and the cubes of the major axes—should represent the above-named elements of magnitude, density, &c., for the succession of the several planetary bodies in each group, in connection with or dependence on their respective solar distances. Although it is true that the planet which is nearest to the sun (Mercury) is also the densest, and even six or eight times as dense as the exterior planets, Jupiter, Saturn, Uranus, and Neptune; yet the order of succession between Venus, Earth, and

Mars, and between Jupiter, Saturn, and Uranus, is very far from being a regular one. We see that, in general, the absolute magnitudes, as Kepler had already remarked (Harmonice Mundi, V. iv. p. 194; Kosmos, Bd. i. S. 389; Eng. ed. p. xvi. Note 38), increase with the distance; but this, though generally true, is not true of each case in particular, for Mars is less than the Earth, Uranus less than Saturn, Saturn less than Jupiter, and Jupiter, the largest of all the planets known to us, is immediately preceded by a group of planets whose disks are scarcely measurable from their minuteness. The velocity of rotation does indeed increase generally with the solar distance; but yet the rotation of Mars is slower than that of the Earth, and that of Saturn slower than that of Jupiter.

The world of forms can, I repeat, be only depicted according to the actual relations of space existing in nature, not as the necessary object of intellectual deduction or of an already recognised causal sequence. In this respect no natural law has been discovered in celestial space, any more than in the geographical position of the culminating points of mountain chains, or in the particular configuration of continents on the surface of our globe. They are facts in Nature which have issued from the conflict of tangential and attracting forces of manifold character, acting under conditions which remain unknown to us. We here find ourselves approaching with eager but unsatisfied curiosity the mysterious domain of formation. The questions before us relate, in the strict sense of the words, to universal events, to cosmical processes taking place in intervals of time to us immeasurably small.

If the planets have been gradually formed from revolving rings of vaporous matter, when this matter began to

condense towards different points of predominating attraction, it must have passed through an almost infinite succession of states in order to form some simple and other intersecting orbits; and planets varying so greatly in magnitude, ellipticity, and density, some accompanied by, and others destitute of moons, and even in one case a series of satellites united in a solid ring. The present form of things, and the exact numerical determination of their mutual relations, have not as yet conducted us to a knowledge of the states previously passed through, nor to a clear insight into the conditions under which they have arisen. Yet these conditions are not therefore to be termed accidental, as man is prone to call all which he cannot yet explain genetically.

3. *Absolute and apparent magnitudes, and external figure.*—The diameter of the largest of all the planets, Jupiter, is 30 times as great as that of Mercury (the smallest of all the planets having securely measurable disks), and almost 11 times as great as that of the Earth: as compared with the Sun, its diameter is nearly as 1 : 10—a ratio nearly similar, inversely, to that between it and the Earth. It has been stated, perhaps erroneously, that the difference of size between meteoric stones, which many are inclined to regard as small planetary bodies—and Vesta, which, according to a measurement of Mädler's, has a diameter of 264* geographical miles (320† geographical miles less than the diameter of Pallas, according to Lamont)—is not more considerable than the difference of size between Vesta and the Sun. According to these proportions, there should be meteoric

* 66 German geographical miles.

† 80 German geographical miles.

stones of 517 German feet in diameter: igneous meteors have certainly been seen of 2600 feet in diameter before the explosion.

The connection between the degree of compression at the poles and the velocity of rotation is most strikingly shown by a comparison between the Earth, as a planet of the *inner* group, and Jupiter and Saturn belonging to the outer group of planets. For the Earth, period of rotation $23^h\ 56^m$, compression $\frac{1}{299}$; for Jupiter, period of rotation $9^h\ 55^m$, compression, according to Arago, $\frac{1}{17}$,—according to John Herschel, $\frac{1}{15}$; for Saturn, period of rotation $10^h\ 29^m$, compression $\frac{1}{10}$. But Mars, whose rotation is *slower* than that of the Earth by 41 minutes, has, even assuming a much smaller result than that adopted by William Herschel, still a probably much greater compression than the Earth. May this anomaly, since the form of the superficies of an elliptic spheroid should correspond to the velocity of rotation, be founded on a different law of increasing density from the surface to the centre in the two planets, or in the possible circumstance of the consolidation of the fluid surface of some planets having taken place before they had assumed the figure corresponding to their velocity of rotation? On the form of the ellipticity of our planet depend, as theoretical astronomy demonstrates, the important phenomena of the retrogression of the equinoctial points, or the apparent progression of the heavenly bodies, termed the "Precession of the Equinoxes," "Nutation" (libration of the Earth's axis)— and the change of the obliquity of the ecliptic.

The apparent diameters of the planets are determined by their absolute magnitudes, and by their distances from the Earth: the following is the order of arrangement which

corresponds to their absolute or true magnitudes, beginning with the smallest :—

The group of the smaller planets, of which Pallas and Vesta appear to be the largest : then—

| | |
|---|---|
| Mercury. | Neptune. |
| Mars. | Uranus. |
| Venus. | Saturn. |
| Earth. | Jupiter. |

At their respective mean distances from the Earth, Jupiter has an apparent equatorial diameter of 38″ 4 ; the equatorial diameter of Venus, which is nearly of the same magnitude as the Earth, being only 16″ 9 ; and that of Mars 5″ 8. At the inferior conjunction, however, of Venus, the apparent diameter of the disk increases to 62″ ; whereas that of Jupiter, when in opposition, only increases to 46″. It is here necessary to remark that the place in the orbit of Venus at which that planet appears brightest falls between its inferior conjunction and its greatest digression from the sun ; at which time the narrow bow of light, by reason of its greatest proximity to the Earth, gives its most intense light. On the average, Venus shines brightest, and, in the absence of the sun, even casts shadows when she is 40° east or west of the sun ; her apparent diameter is then only 40″, and the greatest breadth of her illuminated portion scarcely 10′.

Apparent diameters of 7 planets :—

| | | | |
|---|---|---|---|
| Mercury, at mean distance, | 6″·7 | (oscillates from | 4·″4 to 12″) |
| Venus „ | 16·9 | ( „ | 9·5 „ 62) |
| Mars „ | 5·8 | ( „ | 3·3 „ 23) |

| | | | |
|---|---|---|---|
| Jupiter, at mean distance, | 38″·4 | (oscillates from | 30″·0 to 46″) |
| Saturn ,, | 17 ·1 | ( ,, | 15·0 ,, 20) |
| Uranus ,, | 3 ·9 | | |
| Neptune ,, | 2 ·7 | | |

Volumes of the planets relatively to that of the Earth :—

| | | |
|---|---|---|
| Mercury . . | as | 1 : 16·7 |
| Venus . . | ,, | 1 : 1·05 |
| Earth . . . | ,, | 1 : 1 |
| Mars . . . | ,, | 1 : 7·14 |
| Jupiter . . . | ,, | 1414 : 1 |
| Saturn . . . | ,, | 735 : 1 |
| Uranus . . . | ,, | 82 : 1 |
| Neptune . . | ,, | 108 : 1 ; |

while the volume of the Sun is to that of the Earth as 1407124 : 1. Small alterations in the measurements of the diameters increase the resulting volumes in the ratio of the cubes.

These planetary bodies, which, by their changes of place, enliven and vary in an agreeable manner the aspect of the starry heavens, produce on us an impression which is in each case the conjoint result of the magnitudes of their disks and their proximity, of the colour of their light, the scintillation of some among them in particular positions, and the peculiar manner in which their different surfaces reflect the solar light. Whether the intensity and quality of their light may be further modified by a feeble evolution of light from their own surfaces, is a problem which still remains to be solved.

4. *Arrangement of the planets according to their*

*distances from the Sun.*—The following table gives all the planets discovered hitherto, with their mean distances from the central body, taking, as has always been customary in astronomy, the mean solar distance of the Earth (20682000 German, or 82728000 Eng. geographical miles) as unity. In describing the planets separately, their greatest and least distances from the sun will be given—*i. e.* their distances when in aphelion and in perihelion, or when the planet, in the course of its motion in the ellipse of which the sun occupies the focus, is respectively at either end of the major axis (the line of the apsides), viz. the end which is farthest from, or that which is nearest to, the focus. By the *mean* solar distance of a planet, which is that which we are now speaking of, we understand the mean between the greatest and the least distance, or half the major axis of the planet's orbit. The numerical data already given, and also those which follow, are taken for the most part from Hansen's careful recapitulation of the planetary elements, in Schumacher's Jahrbuch for 1837. Where the data are related to time, they apply, in the case of the older-known and larger planets, to the year 1800, but in that of Neptune to 1851: the Berlin Astronomische Jahrbuch for 1853 has also been made use of. For the statements relating to the smaller planets I am indebted to the friendship of Dr. Galle; they all refer to very recent epochs.

Distances of the planets from the Sun:—

| | |
|---|---|
| Mercury . . . . . | 0·38709 |
| Venus . . . . . | 0·72333 |
| Earth . . . . . | 1·00000 |
| Mars . . . . . | 1·52369 |

Small Planets.

| | |
|---|---|
| Flora | 2·202 |
| Victoria | 2·335 |
| Vesta | 2·362 |
| Iris | 2·385 |
| Metis | 2·386 |
| Hebe | 2·425 |
| Parthenope | 2·448 |
| Irene | 2·553 |
| Astræa | 2·577 |
| Egeria | 2·579 |
| Juno | 2·669 |
| Ceres | 2·768 |
| Pallas | 2·773 |
| Hygeia | 3·151 |
| Jupiter | 5·20277 |
| Saturn | 9·53885 |
| Uranus | 19·18239 |
| Neptune | 30·03628 |

The simple observation of the rapid diminution of the periods of revolution from Saturn and Jupiter to Mars and Venus, had, on the assumption of the planets being attached to revolving spheres, led very early to conjectures respecting the distances of these spheres from each other. As no methodical system of observation and measurement appears to have existed among the Greeks prior to Aristarchus of Samos and the establishment of the Alexandrian Museum, there arose great diversities in the hypotheses formed concerning the order of the succession of the planets and their relative distances; whether, according to the most

prevailing system, these distances were taken from the Earth fixed in repose in the centre, or, according to the Pythagoreans, from the "Hearth of the Universe," the Hestia. Great fluctuations of opinion took place more particularly in respect to the position of the Sun—viz. its position relatively to the inferior planets and to the Moon ([510]). The Pythagoreans, in whose view *number* was the source of knowledge and constituted the essence of things, applied their theory of numbers, and their all-pervading doctrine of numerical proportions, to the geometric consideration of the five early recognised regular bodies, to the musical intervals of tones determining harmony and forming different families of sound, and even to the structure of the Universe itself—deeming that the moving, and, as it seemed, oscillating planets, causing waves of sound, must, by the harmonic ratios of their intervals of space, call forth a "music of the spheres." "This music," they added, "would be audible to the human ear, were it not that be-"cause it is perpetual, and because, therefore, man is accus-"tomed to it from earliest infancy, it remains unheeded" ([511]). The harmonic portion of the Pythagorean doctrine of numbers accorded well with the figurative representation of the Cosmos in the spirit of the Timæus of Plato; for "to Plato the Cosmogony appeared the work of the union effected between opposite primeval causes by the power of Harmony" ([512]). Plato even personified the Harmony of the Universe or music of the spheres by placing in each of the planetary orbs Syrens, by whose songs, and by the support of the stern daughters of Necessity, the three Fates, the perpetual gyratory movement of the spindles of the Universe was maintained ([513]). Representations of this kind of the

Syrens, or sometimes in their place the Muses, as celestial songstresses, have been preserved in several remains of antique art, particularly on cut stones. In Christian antiquity, and throughout the middle ages, from Basil the Great to Thomas Aquinas and Petrus Alliacus, we find frequent allusions,—most often, however, in terms of censure,—to this idea of the Harmony of the Spheres (514).

All the Pythagorean and Platonistic views of the Universe, both the geometric and the musical, re-awoke at the end of the sixteenth century in the imaginative Kepler. He built up the planetary system, first in the Mysterium cosmographicum, on the basis of five regular solids which could be placed in the intervals between the planetary spheres; and next, in the Harmonice Mundi, according to the intervals of musical notes (515). Persuaded of the conformity to law of the relative distances of the planets, he thought to solve the problem which he had thus proposed to himself by a happy combination of his earlier and his later views. It is remarkable that Tycho de Brahe, who, on all other occasions, we find so rigidly attached to actual observation, had, before Kepler, expressed the opinion, contested by Rothmann, that the revolving cosmical bodies may, by agitating the celestial air (that which we now call the "resisting medium"), produce musical sounds (516). It appears to me, however, that the analogies between the relations of musical tones or notes and the distances of the planets, however long and laboriously traced or sought after by Kepler, yet in the mind of that ingenious thinker never passed out of the domain of abstractions. He, indeed, at one time rejoices in having discovered, to the greater glory of the Creator, musical relations of num-

ber in cosmical relations of space. In a kind of poetic rapture, he makes Venus, together with the Earth, play "major," "Dur," when in aphelion, and "minor," "Moll," in perihelion; and even says that the highest tone of Jupiter and that of Venus must unite in the "Moll," or "minor consonance." But, notwithstanding all these frequently employed, and yet merely figurative or symbolical, expressions, Kepler says distinctly—"Jam soni in cœlo nulli existunt, nec tam turbulentus est motus, ut ex attritu *auræ cœlestis* eliciatur stridor" (Harmonice Mundi, lib. v. cap. 4). Here, then, is again mention of the rare and serene celestial air (aura cœlestis).

The comparison of the intervals between the planets, with the regular solids which he considered ought to fit into those intervals, had encouraged Kepler to extend his hypotheses even to the heaven of the fixed stars (517). On the discovery of Ceres and of the other small planets, Kepler's Pythagorean combinations were vividly recalled to recollection, on account of his previously almost forgotten expressions respecting the probable existence of a yet unseen planet in the great gap between Mars and Jupiter: (motus semper distantiam pone sequi videtur: atque ubi magnus hiatus erat inter orbes, erat et inter motus).

In his Introduction to the Mysterium cosmographicum, Kepler says—"I have become bolder, and now place a new planet between Jupiter and Mars, as well as"—a less happy hypothesis, and one which long remained unnoticed (518)—"another planet between Venus and Mercury: probably it is the extraordinary smallness of both which has caused them to remain unseen" (519). Subsequently Kepler found that he did not require these new planets for the arrangement of his solar

system according to the properties of his five regular solids; it was only necessary to do a little violence to the distances of the old planets. ("Non reperies novos et incognitos Planetas, ut paulo antea, interpositos, non ea mihi probatur audacia; sed illos veteres *parum admodum luxatos.*"—Myst. Cosmogr. p. 10). The intellectual tendencies of Kepler had so great an analogy with those of the Pythagoreans, and still more with those manifested in the Timæus of Plato, that as Plato (Cratyl. p. 409) found in the seven planetary spheres the differences of colours, as well as those of musical notes, so Kepler (Astron. opt. cap. 6, p. 261) made experiments, in which he attempted to imitate, on a variously illuminated table, the colours of the planets. Even the great Newton, ever so faithful to Reason, and so severe in all his inductions, was yet, as Prevost has already remarked, inclined to refer the dimensions of the seven colours of the spectrum to the diatonic scale ([520]).

The hypothesis of the existence of still unknown members of the planetary series of the solar system reminds us of the ancient Greek opinion of there being far more than five planets, that being only the number of those which had been observed, while many others remained hidden by their position, and the feebleness of their light. Such a statement has been ascribed in particular to Artemidorus of Ephesus ([521]). Another ancient Hellenic, and perhaps even Egyptian belief, appears to have been "that the celestial bodies which we now behold have not all been always seen by man." Such a physical, or rather historical, myth is connected with the particular form of vain-gloriousness which leads some nations and races to attribute to themselves an extraordinary degree of antiquity. Thus the pre-

hellenic Pelasgian inhabitants of Arcadia called themselves "Proselenes," because they boasted of having come into the country before the Moon accompanied the Earth. Pre-hellenic and pre-lunar were synonymous. The appearance of a heavenly body was described as a celestial event, as Deucalion's flood was a terrestrial event. Apuleius (Apologia, Vol. ii. p. 494, ed. Oudendorp; Kosmos, Bd. ii. S. 439, Anm. 53; Eng. ed. p. lvii. Note 293) made Deucalion's flood extend to the Gætulian Mountains of Northern Africa. In Apollonius Rhodius—who, according to the favourite manner of Alexandrian writers, delighted in imitating ancient modes of speech—it is said of the early settlement of the Egyptians in the valley of the Nile—"As yet not all the heavenly bodies journeyed over the celestial vault; the children of Danaus had not yet appeared, nor Deucalion's race" ([522]). This important passage elucidates the boast of the Pelasgic Arcadians.

I conclude these considerations respecting the distances and dimensions of the planets, with what has been termed a law, although it does not indeed deserve the name, and which Lalande and Delambre have called a play upon numbers, and others a mnemonic contrivance, or help to the memory. Our meritorious Berlin astronomer, Bode, had been much occupied with this subject, especially at the time of the discovery of Ceres by Piazzi, which discovery, it should be remembered, was in no way effected by means of this supposed law, but was rather occasioned by an error of the press in Wollaston's star-catalogue. If the discovery were to be regarded as the fulfilment of a prophecy, then Kepler's prediction, spoken of above, which is more than a century and a half antecedent to Titius and Bode, ought

not to be forgotten. Although, in his popular and highly useful "Introduction to the Knowledge of the Starry Heavens," Bode had himself said distinctly that he had taken the law of the distances from a translation of Bonnet's "Contemplation de la Nature" made by Professor Titius at Wittenberg, yet it has been commonly called Bode's law, and the name of Titius has been seldom mentioned in connection with it. In a note appended by the latter to the chapter on the Structure of the Universe ([523]), he says—"If we examine the distances of the planets, we find in almost all a proportion between their distances apart and the increase of their corporeal magnitudes. If the distance from the Sun to Saturn gives 100 parts, then Mercury is distant 4 such parts from the Sun, Venus $4+3=7$ parts from the Sun, the Earth $4+6=10$, Mars $4+12=16$. But from Mars to Jupiter we come to a departure from this progression previously so exact (!). Beyond Mars there follows a space of $4+24=28$ such parts; but here we find neither primary planet nor satellite. Can we suppose that the Great Architect has left this space void? We must not doubt that it is occupied; it may be by the hitherto undiscovered satellites of Mars, or perhaps Jupiter may have additional satellites that have never yet been seen by any telescope. From this unknown interval (unknown as to that which occupies it) the space to Jupiter is $4+48=52$. Then follows Saturn at the solar distance of $4+96=100$ parts—an admirable proportion." Titius, therefore, was inclined to occupy the interval between Mars and Jupiter not with the one, but (as is actually the case) with several bodies; but he conjectured them to be satellites, not planets.

It is nowhere said how the translator and commentator of

Bonnet arrived at the number 4 for the orbit of Mercury. Perhaps he only selected it in order to have for Saturn, which was then the most distant known planet (its distance is 9·5, therefore nearly 10·0), exactly 100 parts in connection with the easily divisible numbers 96, 48, 24, &c. This is more probable than that he should have made the series by beginning with the nearer planets. Even in the last century, this law of doubling, beginning not from the Sun but from Mercury, could not be affirmed to agree sufficiently with the true distances of the planets as then known to us. The distances of Jupiter, Saturn, and Uranus, do indeed in reality approach very nearly to the rate of doubling; but since the discovery of Neptune, which is much too near to Uranus, the defect of the progression has become strikingly obvious ([524]).

What has been called the law of Vicarius Wurm of Leonberg, and has been sometimes distinguished from that of Titius and Bode, is a simple correction of the latter law, applied by Wurm to the solar distance of Mercury and to the difference between the solar distances of Mercury and Venus. With a nearer approximation to the truth, he makes the solar distance of Mercury 387, and that of Venus 680, the Earth being 1000 ([525]). On the occasion of the discovery of Pallas by Olbers, Gauss, in a letter to Zach (Oct. 1802), already passed a striking and just sentence on the so-called law of distances. He says—"Contrary to the nature of all truths which deserve the name of laws, that of Titius applies only in a very cursory manner to most of the planets, and (which does not appear to have been before remarked) not at all to Mercury. It is clear that the series 4, 4+3, 4+6, 4+12, 4+24, 4+48, 4+96, 4+192,

with which the distances should agree, is not even a continuous series at all. The number preceding $4+3$ ought to be not 4—*i. e.* $4+0$—but $4+1\frac{1}{2}$. So between 4 and $4+3$ there should be an indefinite number of intermediate quantities; or, as Wurm expresses it, for $n=1$ the result of $4+3\times 2^{n-2}$ is not 4, but $5\frac{1}{2}$. Attempts to discover such approximate agreements in Nature are, however, by no means to be censured; the greatest men of all periods have been fond of such lusus ingenii."

5. *Masses of the Planets.*—The masses of the planets are investigated by means of their satellites (where such exist), of their mutual perturbations, or of the effects suffered or produced by a comet of short period. Thus in 1841 Encke determined, from the perturbations undergone by the comet which bears his name, the previously unknown mass of Mercury. The same comet affords a prospect of future corrections for the mass of Venus. The perturbations of Vesta are made use of for Jupiter. The mass of the Sun being taken as unity, we have (according to Encke's fourth memoir on the comet of Pons, in the "Schriften der Berliner Akademie der Wissenschaften" für 1842, S. 5):—

| | |
|---|---|
| Mercury . . . . | $\frac{1}{4865751}$ |
| Venus . . . . . | $\frac{1}{401839}$ |
| Earth . . . . . | $\frac{1}{359551}$ |
| Earth and Moon together . | $\frac{1}{355499}$ |
| Mars . . . . . | $\frac{1}{2680337}$ |
| Jupiter with his satellites . . | $\frac{1}{1047 \cdot 879}$ |
| Saturn . . . . . | $\frac{1}{3501 \cdot 6}$ |
| Uranus . . . . . | $\frac{1}{24605}$ |
| Neptune . . . . | $\frac{1}{14446}$ |

Still larger, although remarkably near to the truth, was the mass ($\frac{1}{9322}$) deduced for Neptune by Le Verrier from his ingenious calculations previous to the actual discovery of the planet by Galle. The following is the arrangement of the planets according to their masses, beginning with the least (omitting the smaller planets, Ceres, Pallas, Juno, &c.), and proceeding in increasing order :—Mercury, Mars, Venus, Earth, Uranus, Neptune, Saturn, and Jupiter.

It will be seen that this order of succession (as in the case of the volumes and densities) is by no means identical with that of the distances from the central body.

6. *Density of the Planets.*—Employing the previously given volumes and masses, we obtain for the densities of the planets (taking respectively the densities of the Earth and that of Water as unity) the following numerical ratios :—

| Planets. | Ratio to the density of the Earth. | Ratio to the density of Water. |
|---|---|---|
| Mercury . . . | 1·234 | 6·71 |
| Venus . . . . | 0·940 | 5·11 |
| Earth . . . . | 1·000 | 5·44 |
| Mars . . . . . | 0·958 | 5·21 |
| Jupiter . . . . | 0·243 | 1·32 |
| Saturn . . . . | 0·140 | 0·76 |
| Uranus . . . . | 0·178 | 0·97 |
| Neptune . . . | 0·230 | 1·25 |

In the above table the comparison of the densities of the different planets with that of water is based on the density of our own globe. This was given by Reich's experiments with the torsion-balance made at Freiberg, 5·4383; the analogous earlier experiments of Cavendish give, according

to the more exact re-calculation of Francis Baily, the very similar result of 5·448, and Baily's own experiments 5·660. We see that the density of Mercury, according to Encke's determination of its mass, is near that of the other planets of medium magnitude.

The above table reminds us again of the division, to which I have already repeatedly alluded, of the planets into two groups separated from each other by the zone of the small planets. The differences between the densities of Mars, Venus, the Earth, and even Mercury, are very small, and there is nearly as great a similarity between those of the far less dense remoter planets—Jupiter, Neptune, Uranus, and Saturn. The density of the Sun (0·252), that of the Earth being taken as =1 (1·37, therefore, when Water is taken as =1) is a little greater than the densities of Jupiter and Neptune. The following is the order of succession of the sun and planets arranged according to increasing density ([526]) :—Saturn, Uranus, Neptune, Jupiter, Sun, Venus, Mars, Earth, Mercury.

Although the densest planets are, on the whole, those nearest to the sun, yet, taken individually, the densities of the several planets are by no means proportional to their solar distances, as Newton was inclined to assume ([527]).

7. *Sidereal period of revolution and rotation round the axis.*—We shall content ourselves here with giving the sidereal, or true periods of revolution of the planets in relation to the fixed stars or to some particular point in the heavens. In the interval of time occupied by such a revolution the planet performs 360 complete degrees round the sun. The sidereal revolutions are very distinct from the tropical and synodical, of which the former relate to the return of the vernal equinox, and the latter to the difference

of time between two successive conjunctions or oppositions.

| Planets. | Sidereal periods of revolution. | Rotation. | | | |
|---|---|---|---|---|---|
| | days. | d. | h. | m. | s. |
| Mercury | 87·96928 | | | | |
| Venus | 224·70078 | | | | |
| Earth | 365·25637 | 0 | 23 | 56 | 4 |
| Mars | 686·97964 | | 0 | 37 | 20 |
| Jupiter | 4332·58480 | 0 | 9 | 55 | 27 |
| Saturn | 10759·21981 | 0 | 10 | 29 | 17 |
| Uranus | 30686·82051 | | | | |
| Neptune | 60126·7 | | | | |

In another, and perhaps still more readily intelligible form, the true periods of revolution are—

| | Days. | Hours. | Minutes. | Seconds. |
|---|---|---|---|---|
| Mercury | 87 | 23 | 15 | 46 |
| Venus | 224 | 16 | 49 | 7 |
| Earth | 365 | 6 | 9 | 10·7496 |

From the last-named of these periods (that of the Earth) the tropical period of revolution, or the length of the solar year, is found to be 365·24222, or $365^d$, $5^h$, $48^m$, $47^s$·8091: by the effect of the precession of the equinoxes the length of the solar year becomes $0^s$·595 shorter in the course of 100 years:—

| | Years. | Days. | Hours. | Minutes. | Seconds. |
|---|---|---|---|---|---|
| Mars | 1 | 321 | 17 | 30 | 41 |
| Jupiter | 11 | 314 | 20 | 2 | 7 |
| Saturn | 29 | 166 | 23 | 16 | 32 |
| Uranus | 84 | 5 | 19 | 41 | 36 |
| Neptune | 164 | 225 | 17 | | |

The rotation is most rapid in the very large exterior planets which have long periods of revolution, and slower in the smaller planets which are nearer to the sun. The period of revolution varies considerably in the asteroids, or small planets between Mars and Jupiter, and will be stated subsequently in the account given of each; it is sufficient at present to remark that it is longest in Hygeia and shortest in Flora.

8. *Inclination of the planetary orbits and axes of rotation.*—Next to the masses of the planets the inclination and excentricity of their orbits are among the most important elements on which the perturbations depend. Their comparison in the several series of the inner, the small middle, and the outer planets (from Mercury to Mars, from Flora to Hygeia, and from Jupiter to Neptune), presents similarities and contrasts which lead to considerations respecting the formation of these bodies, and their secular variations or changes connected with long periods of time. The planets which revolve in such different elliptic orbits are all situated in different planes. In order to render a numerical comparison possible they are referred to a fundamental plane, either fixed, or moveable according to a given law. It is considered most convenient to take for this plane either the ecliptic (the path which the Earth really passes over), or the equator of the terrestrial spheroid. In addition to these planes, the subjoined table contains the inclinations of the axes of rotation of the planets to their own orbits, so far as these are known on the evidence of tolerably secure investigation:—

| Planets. | Inclination of the Planetary Orbits to the Ecliptic. | Inclination of the Planetary Orbits to the Earth's Equator. | Inclination of the Axes of the Planets to their Orbits. |
|---|---|---|---|
| Mercury . . . | 7° 0′ 5″.9 | 28° 45′ 8″ | |
| Venus . . . | 3 23 28 ·5 | 24 33 21 | |
| Earth . . . | 0 0 0 | 23 27 54.8 | 66° 32 |
| Mars . . . . | 1 51 6 .2 | 24 44 24 | 61 18 |
| Jupiter . . . | 1 18 51 .6 | 23 18 28 | 86 54 |
| Saturn . . . | 2 29 35 .9 | 22 38 44 | |
| Uranus . . . | 0 46 28 ·0 | 23 41 24 | |
| Neptune . . . | 1 47 | 22 21 | |

The small planets have been omitted, because they will be treated subsequently as a detached group. With the exception of Mercury, which is situated so near the sun, and the inclination of whose orbit to the ecliptic (7° 0′ 5″·9) is very nearly the same as that of the sun's equator 7° 30′), we see that the inclinations of the other seven planetary orbits oscillate between $0\frac{3}{4}°$ and $3\frac{1}{2}°$. In respect to the position of each planet's axis of rotation relatively to its own orbit, it is Jupiter which approaches most nearly to the extreme case of perpendicularity. In Uranus, on the other hand, to judge by the inclination of the paths of the satellites, the axis of rotation of the planet almost coincides with the plane of its orbit.

As it is on the inclination of the Earth's axis to the plane of its orbit, therefore on the obliquity of the ecliptic (*i. e.* on the angle which the apparent path of the sun makes at its intersection with the terrestrial equator,) that the distribution and duration of the seasons, the altitudes of the sun in different latitudes, and the length of the day depend; so

this element is of the most essential importance in determining "astronomical climates"—*i. e.* the temperature of the globe, so far as that temperature is a function of the altitude attained by the sun at noon, and of the length of the time during which the sun remains above the horizon. With a considerably greater obliquity of the ecliptic, or supposing the terrestrial equator to be perpendicular to the Earth's orbit, every place on the Earth would once a year have the sun in its zenith, even under the poles, and for a longer or shorter time would not see the sun rise. Under every latitude the difference of summer and winter (as well as of the length of day) would reach the maximum of contrast. In every part of the Earth the climates would be in the highest degree of the description which we call "excessive;" their extreme character would be only very slightly modified by the extraordinarily complicated series of rapidly changing currents of air which would be produced. In the reverse case, that of the obliquity of the ecliptic being null, or the terrestrial equator coinciding with the ecliptic, the difference of seasons and of length of day would everywhere cease, because the sun's apparent course would be uninterruptedly in the equinoctial line. The inhabitants of the poles would never cease to see the sun on the horizon. "The mean annual temperature of any point on the Earth's surface would also be that of each day in the year at the same place" ([528]). Such a state of things has been called one of perpetual spring, though the constant equality of day and night seems the only reason for the term. If it existed on the Earth, a great part of the regions which we now call the temperate zone, being deprived of the degree of summer heat which now stimulates and supports vegetation, would be transferred

to the always equable, but by no means desirable or agreeable, "vernal climate" which prevails under the equator on the chain of the Andes near the limits of perpetual snow, and from which I suffered much on the desert mountain plains—the Paramos ([529])—at elevations between ten and twelve thousand French, or about eleven and thirteen thousand English feet, above the sea. The temperature of the air in these regions always oscillates in the day-time between $4\frac{1}{2}°$ and 9° Reaumur, or 42° and 52° Fahrenheit.

The ancient Greeks were much occupied with rough measurements of the obliquity of the ecliptic, and with conjectures respecting its variability, and respecting the influence of the inclination of the terrestrial axis on climate, and on the luxuriance of organic development. These speculations were more especially pursued by Anaxagoras, by the Pythagorean school, and by Œnopides of Chios. The passages which illustrate them, so far as they have come down to us, are indeed scanty and vague; but they enable us to perceive that the development of organic life, and the first appearance of animals, were imagined to have been cotemporaneous with the epoch at which the terrestrial axis began to incline, which inclination also altered the habitability of the planet in particular zones. According to Plutarch (de Plac. Philos., ii. 8), Anaxagoras believed "that the World, after it had began and had brought forth living beings from its bosom, spontaneously inclined itself towards the noon or southern side." To the same effect, Diogenes Laertius (ii. 9) says, when speaking of the opinions of the Clazomenian philosopher—"The stars had first begun to revolve, as it were, round a dome, so that what appeared the pole was vertically above the Earth; but subsequently they assumed an oblique

direction." The obliquity of the ecliptic was regarded as a cosmical *event*, an alteration which took place suddenly no allusion was made to a subsequent progressive change.

The description of the two extreme or opposite cases, to which the planets Uranus and Jupiter approximate most nearly, is suited to remind us of the alterations which the increasing or decreasing obliquity of the ecliptic would produce in the meteorological relations of our planet, and in the development of organic forms, if this increase and decrease were not restricted within very narrow limits. The recognition of these limits has been the object of the great labours of Leonhard Euler, Lagrange, and Laplace, and may be regarded as one of the most brilliant achievements of theoretical astronomy in modern times, and of the degree of perfection to which the higher analysis has been brought. The limits in question are indeed so narrow, that Laplace, in the Exposition du Système du Monde, ed. 1824, p. 303, stated that the obliquity of the ecliptic only oscillates $1\frac{1}{2}°$ on either side of its mean position. This is equivalent to saying that the torrid zone, or the tropic of Cancer, which is its northern boundary, can only approach by that quantity nearer to the part of the Earth in which we live [530], or that, leaving out of view the effects of the many other causes of meteorological perturbations, Berlin might be gradually transferred from its present isothermal line to that of Prague. The implied elevation of the mean annual temperature would hardly be more than one degree of the centigrade thermometer (1·8° Fah.) [531]. Biot, though also believing the variations of the obliquity of the ecliptic to be restricted within narrow limits, yet deems it more advisable not to attempt at present to assign to them definite numerical values. He says—"La

diminution lente et séculaire de l'obliquité de l'écliptique offre des états alternatifs qui produisent une oscillation éternelle comprise entre des limites fixes. La théorie n'a pas encore pu parvenir à determiner ces limites; mais d'après la constitution du système planétaire, elle a demontré qu'elles existent et qu'elles sont *tres peu étendues*. Ainsi à ne considérer que le seul effet des causes constantes qui agissent actuellement sur le système du monde, on peut affirmer que le plan de l'écliptique *n'a jamais coincidé* et ne *coincidera jamais* avec le plan de l'équateur, phénomène qui, s'il arrivait, produirait sur la terre le (prétendu!) printemps perpétuel" (Biot, Traité d'Astronomie Physique, 3me éd. 1847, T. iv. p. 91).

While the Nutation of the terrestrial axis discovered by Bradley depends solely upon the influence of the Sun and the Earth's own satellite upon the compressed form of our planet at its poles, the increase and decrease of the obliquity of the ecliptic is a consequence of the varying positions of all the planets. These are at present so distributed that their joint action on the Earth's path or orbit produces a diminution of the obliquity, which diminution amounts at the present time, according to Bessel, to 0″·457 annually. After the lapse of several thousand years the places of the planetary orbits and their nodes (points of intersection on the ecliptic) will be so different that the advance, or precession, of the equinoxes will be changed into a retrogression, and thereby produce an increase of the obliquity of the ecliptic. Theory teaches that this increase and decrease occupy periods of very unequal duration. The oldest astronomical observations which have been preserved to us with exact numerical data extend back to the year 1104 B.C., and testify the

high antiquity of Chinese civilisation. There are remains of Chinese literature scarcely a century less ancient; and a regular historic chronology reaches back (according to Edouard Biot) to 2700 years before our era (532). Under the Regency of Tscheu-kung, brother of Wu-wang, the length of the sun's meridian shadow (533) was measured at the summer and winter solstice, with an 8-foot gnomon, at the town of Lo-jang, to the south of the Yellow River, in latitude 34° 46′ (the present name of the town is Ho-nang-fu, in the Province of Ho-nan.) These measurements gave the obliquity of the ecliptic 23° 54′; being 27′ greater than it was in 1850. The observations of Pytheas and Eratosthenes at Marseilles and Alexandria are six and seven centuries later. We possess four results respecting the amount of the obliquity of the ecliptic previous to our era, and seven results intermediate between that period and Ulugh Beg's observations at the Observatory of Samarcand. The theory of Laplace agrees admirably, having differences which are sometimes plus and sometimes minus, with the observations extending over a period of almost 3000 years. We are more fortunate in the knowledge of the early Chinese measurements of the length of the solar shadow, as the writing containing the account escaped, we know not how or why, from the great destruction of books which took place from motives of fanaticism, by the orders of the Emperor Shi-hoang-ti of the Tsin dynasty, 246 years before our era. As, according to the researches of Lepsius, the commencement of the 4th Egyptian dynasty, which began with the reigns of the pyramid-building kings, Chufu, Shafra, and Menkera, was 23 centuries anterior to the solstitial observation at Lo-jang, we may assume with very great probabi-

lity—seeing the high degree of intellectual cultivation of the Egyptian nation, and its early construction of calendars —that similar measurements had been made at least as early in the Valley of the Nile; but none such have come down to us. Even the Peruvians—although they had made less advances than the Mexicans and the Muyscas (inhabitants of the mountains of New Granada) in the improvement of calendars and intercalation—had gnomons in which the style was surrounded by a circle drawn upon a very even surface. These gnomons were placed in the interior of the great temple of the Sun at Cuzco, as well as in many other parts of the Peruvian empire: the one at Quito, situated almost directly under the equator, used to be decorated with flowers at festivals held at the equinoxes, and was regarded with particular honour ([534]).

9. *Excentricity of the planetary orbits.*—The form of the elliptic orbits is determined by the greater or less distance of the two foci from the centre of the ellipse. This distance—or the degree of excentricity of the planetary orbits expressed in parts of their semi-axes—varies from 0·006 in Venus (differing, therefore, very little from a circle) and 0·076 in Ceres, to 0·205 in Mercury and 0·255 in Juno. The least excentric orbits are successively those of Venus, Neptune, and the Earth, the last of which is now diminishing at the rate of 0·00004299 in a hundred years, while the minor axis is increasing; then follow Uranus, Jupiter, Saturn, Ceres, Egeria Vesta, and Mars. The most excentric orbits are those of Juno (0·255), Pallas (0·239), Iris (0·232), Victoria (0·217), Mercury (0·205), and Hebe (0·202). In some planets—as Mercury, Mars, and Jupiter —the excentricities are increasing; while in others—as

Venus, the Earth, Saturn, and Uranus—they are decreasing. The following table gives the excentricities of the larger planets according to Hansen for the year 1800; the excentricities of the 14 small planets will be given subsequently, together with the other elements of their orbits, for the middle of the 19th century:—

| | |
|---|---|
| Mercury . . . . | 0·2056163 |
| Venus . . . . | 0·0068618 |
| Earth . . . . . | 0·0167922 |
| Mars . . . . . | 0·0932168 |
| Jupiter . . . . | 0·0481621 |
| Saturn . . . . | 0·0561505 |
| Uranus . . . . | 0·0466108 |
| Neptune . . . . | 0·0087195 |

The movement of the major axis (line of the apsides) in planetary orbits, whereby the place of the perihelion is altered, takes place always in one direction. It is a change in the position of the line of the apsides which would require more than a hundred thousand years to complete its cycle, and is to be thoroughly distinguished from the changes of form or of ellipticity suffered by the orbits. The question has been mooted whether, in the course of several thousand years, the increasing value of this element could modify in a considerable degree the temperature of the Earth, in respect to its amount and distribution in the different parts of the day and of the year? Whether there might not be found in these regularly and continually acting astronomical causes a partial solution of the great geological problem of the remains of tropical vegetable and animal forms in the present cold zone? The same mathematical

reasonings which have excited apprehensions, in respect to the position of the apsides,—the form of the planetary elliptical orbits (according as they approximate to a circle on the one hand, or to a comet-like degree of excentricity on the other),—the inclination of the axes of the planets,—the variation of the obliquity of the Ecliptic,—or the influence of the precession of the equinoxes on the length of the year,—also afford, when carried to a higher degree of analytical development, cosmical grounds which counterbalance such apprehensions. The major axes and the masses are constant. Periodical return prevents the indefinite accretion of particular perturbations. The excentricities of the two greatest planets, Jupiter and Saturn, besides being in themselves very moderate in amount, undergo, by reason of a reciprocal and compensating influence, alternate increase and decrease, which are restricted within known and determinate and generally narrow limits.

By the alteration in the position of the line of the apsides ([535]), the point at which the Earth is nearest to the Sun tends gradually to change towards the opposite period of the year. If at present the perihelion falls in the beginning of January, and the aphelion six months later, or in the beginning of July, the progressive change of position, or turning movement, of the line of the apsides or major axis of the Earth's orbit, may cause the aphelion, or maximum distance of the Earth from the Sun, to fall in those months which form the winter of the northern hemisphere, and the perihelion, or minimum distance, in our summer; so that in January the Earth would be 700000 German, or 2800000 English, geographical miles (about $\frac{1}{30}$th of the mean distance between the two bodies) farther from the Sun than in July,

which is the converse of what now takes place. At first sight it might seem as if the transference of the period of the greatest proximity of the Earth to the Sun to the opposite season of the year (to our summer instead of our winter) must produce great climatic alterations; but, in fact, supposing such a transference to have been effected, it would follow that the Sun would no longer linger for seven additional days in the northern hemisphere, and would no longer, as at present, pass through the portion of the Ecliptic from the autumnal to the vernal equinox in a space of time shorter by a week than that which it requires for traversing the other half of its path, or from the vernal to the autumnal equinox. The difference of temperature (we here regard, exclusively, astronomical climates, setting aside all physical considerations respecting the relative proportions of sea and land in the different parts of the surface of our globe)—the difference of temperature, I say, apprehended as liable to ensue from a change of the line of the apsides, would disappear almost entirely, from the counterbalancing circumstance, that the point at which our planet is nearest to the Sun is at the same time always that at which it moves most rapidly ([536]). The fine theorem first enounced by Lambert ([537]), according to which the quantity of heat which the Earth receives from the Sun in each part of the year is proportional to the angle described in the same interval of time by the radius vector of the Sun, contains within itself, to a certain degree, a satisfactory reply to the supposition of great climatic change.

We have said that the altered direction of the line of the apsides can exert but little influence on the temperature of the globe; and it may be added that, according to Arago

and Poisson ([538]), the probable alterations of the ellipse formed by the Earth's path are comprised within such narrow limits, that they can only modify the climates of the different terrestrial zones to a very moderate extent, and, moreover, very gradually, and in very long periods. Although the analysis by which these limits are exactly determined is not yet quite completed, yet it has at least shown that the excentricity of the Earth will never be transformed into that of Juno, Pallas, or Victoria.

10. *Strength of the Sun's light on the different planets.*—If we make the strength of the Sun's light on the surface of the Earth =1, we find for—

| | |
|---|---|
| Mercury . . . . . | 6·674 |
| Venus . . . . . | 1·911 |
| Mars . . . . . . | 0·431 |
| Pallas . . . . . | 0·130 |
| Jupiter . . . . . | 0·036 |
| Saturn . . . . . | 0·011 |
| Uranus . . . . . | 0·003 |
| Neptune . . . . . | 0·001 |

Owing to the great excentricities of the orbits of some of the planets, the intensity of light on their surface differs much at their greatest and least distance from the Sun. Thus it is in—

| | | | | |
|---|---|---|---|---|
| Mercury, | when in perihelion, | 10·58; | in aphelion, | 4·59 |
| Mars | „ | 0·52; | „ | 0·36 |
| Juno | „ | 0·25; | „ | 0·09 : |

while the Earth, from the small excentricity of its ellipse, has in perihelion 1·034, and in aphelion 0·967. If the

light of the Sun is nearly 7 times more intense at the surface of Mercury than on that of the Earth, it must be 368 times less intense on Uranus. The ratio of warmth is not here considered, because it is a complicated phenomenon depending on the existence or non-existence of planetary atmospheres, their heights, and special constitution. I will merely allude to the conjecture of Sir John Herschel respecting the temperature at the surface of the moon, "which," he thinks, "may perhaps considerably exceed that of the boiling-point of water" ([539]).

### β. *Satellites.*

General comparative considerations respecting subordinate planets or satellites have been already given with some degree of fulness in the "Picture of Nature" in the 1st volume of Kosmos (S. 99—104, German; p. 86—91, English). At that time (March 1845) only 11 planets and 18 satellites were known. Of asteroids—also called telescopic or small planets—only four had been discovered—viz. Ceres, Pallas, Juno, and Vesta. At the present moment (August 1851) the number of primary planets exceeds that of secondary planets or satellites; for we now know 22 of the former, and 21 of the latter. After a thirty-eight years' interruption of planetary discoveries, from 1807 to December 1845, the discovery of Astræa by Hencke was the first of a long succession by which 10 new small planets have become known to us. Of these, Hencke at Driesen recognised two (Astræa and Hebe); Hind, in London, four (Iris, Flora, Victoria, and Irene); Graham, at Markree Castle, one (Metis); and De Gasparis, at Naples, three (Hygeia, Parthenope, and Egeria). The recognition of the

outermost of all the large planets, Neptune, announced by Le Verrier at Paris, and seen by Galle at Berlin, followed ten months after that of Astræa. Discoveries now succeed each other with such rapidity, that, after the lapse of a few years, a topography of the solar system appears as antiquated as do statistical descriptions of countries after a similar interval.

Of the 21 satellites at present known, 1 belongs to the Earth, 4 to Jupiter, 8 to Saturn (the last discovered of these, Hyperion, the 7th according to distance, was discovered nearly simultaneously on the two sides of the Atlantic by Bond and Lassell), 6 to Uranus (of which the 2d and the 4th are the most securely ascertained), and 2 to Neptune.

The satellites which revolve round the primary planets constitute subordinate systems, in which the planets appear as the central bodies of domains of various and very different dimensions, in which the great solar domain is, as it were, repeated on a smaller scale. According to our present knowledge, the domain of Jupiter has a diameter of 520000 (2080000 Eng.), and that of Saturn 1050000 (4200000 Eng.) geographical miles. In the time of Galileo, when the expression of "Mundus Jovialis" was often used to describe the planet Jupiter and its attendant satellites, these analogies between the solar system and the subordinate systems included within its limits, contributed much to the more rapid and more general reception of the Copernican views. Such analogies also remind us of the repetition of form and position which are often presented to us in organic life.

The distribution of the satellites comprised within the

solar domain is so unequal, that whilst, on the whole, the proportion of the primary planets which have no such attendants to those which are so accompanied is as 3 to 5, the latter class, with the single exception of the Earth, all belong to the outer planetary group, situated beyond the intersecting orbits of the asteroids or small planets. The only satellite in the group of the inner planets situated between the Sun and the asteroids—viz. our Moon—is strikingly large in proportion to the diameter of its primary planet. This proportion is $\frac{1}{3\cdot8}$; whereas the largest of all the satellites of Saturn (the 6th, Titan) is probably only $\frac{1}{15\cdot5}$, and the largest of Jupiter's satellites (the 3d) $\frac{1}{25\cdot8}$ of their respective primaries. We must distinguish in this consideration between relative and absolute magnitude. Our Moon, which is *relatively* so large, is *absolutely* smaller than any of the four satellites of Jupiter; the diameter of the former being 454, and the diameters of the latter respectively 776, 664, 529, and 475 German geographical miles (or the Moon 1816, and Jupiter's satellites 3104, 2656, 2116, and 1900 English geographical miles). The magnitude of the 6th satellite of Saturn differs very little from that of the planet Mars (the diameter of which is 892 German, or 3568 English geographical miles) ([540]). If the question of telescopic visibility depended solely on the diameter of the satellite, and was not also conditional on the proximity to the disk of its primary planet, and the remoteness and nature of its light-reflecting surface, we should have to regard the 1st and 2d of Saturn's satellites (Mimas and Enceladus), and two of the satellites of Uranus, which have been repeatedly seen, as the smallest of

all known satellites. It is, however, safer to designate them merely as the smallest luminous points. At present there appears more reason to believe that the smallest of all planetary bodies, meaning thereby both primary planets and satellites, are to be sought for among the small or telescopic planets ([541]).

The density of satellites is by no means always inferior to that of their primary planets, as is the case in our Moon (whose density, compared to that of the Earth, is as 0·619 to 1), and in Jupiter's 4th satellite. The densest of these satellites, the 2d, is, on the other hand, denser than Jupiter; while the 3d and largest appears to have the same density as the planet itself. Nor do the masses increase with the distance: if the planets have arisen from revolving rings, peculiar causes, which may perhaps ever remain hidden from us, must have occasioned in the various cases larger or smaller, and denser or rarer, accumulations around a nucleus.

The orbits of satellites belonging to the same group have very different excentricities. In the system of Jupiter, the orbits of the 1st and 2d satellites are almost circular; while of those of the 3d and 4th the excentricities amount to 0·0013 and 0·0072. In the system of Saturn, the orbit of the satellite which is nearest to the planet (Mimas) is considerably more excentric than the orbit of Enceladus, or than that of Titan, which has been so accurately determined by Bessel. The excentricity of this, the 6th satellite of Saturn, and the largest and earliest discovered, is only 0·02922. According to all these data, which are deserving of considerable confidence, Mimas is the only satellite whose orbit is more excentric than that of our Moon (0·05484).

Of all known satellites, the Moon is the one whose orbit is the most excentric as compared with that of the primary planet round which it revolves. (Respecting the distances of satellites from their central planets, see Kosmos, Bd. i. S. 102; Eng ed. p. 88-89.) The distance of Saturn's nearest satellite, Mimas, is at present estimated not at 20022, but at 25600 German geographical miles (80088 and 102400 English); whence the resulting distance from Saturn's Ring is somewhat above 7000 German (28000 Eng.) geographical miles, reckoning the breadth of the Ring at 6047 German, or 24188 English, and the distance of the Ring from the surface of the planet 4594 German, or 18376 English, geographical miles [542]. The orbits of satellites present also remarkable anomalies in regard to position, though there is at the same time a certain agreement in this respect in the system of Jupiter, whose satellites all move very nearly in the plane of the equator of their central planet. In the group of Saturn's satellites, 7 revolve nearly in the plane of the Ring, while the outermost or 8th, Japetus, is inclined 12° 14′ to that plane.

In these general considerations respecting the planetary spheres, we have descended from the higher (probably not the highest) system [543]—that of the Sun—to the subordinate partial systems of Jupiter, Saturn, Uranus, and Neptune. As a tendency to generalisation is, as it were, inborn in thoughtful and imaginative man,—as an unsatisfied cosmical anticipation seems to present to him, in the movement of translation of our solar system in space [544], the idea of an ascending relation and subordination; so, on the other hand, the possibility has been suggested that Jupiter's satellites

may be in their turn the central bodies, around which revolve other secondary cosmical bodies which remain unseen by reason of their smallness. Thus individual members of the partial systems, which are principally found in the outer group of primary planets, would have other similar systems subordinated to them. Man's love of systematic arrangement is, it is true, gratified by repetitions of form in descending or ascending order, in images which are the creatures of his own fancy; but in severer and more earnest investigations it is forbidden to confound an ideal with the actual Cosmos, or to mingle the possible with the more sure results of observation.

## SPECIAL NOTICE OF THE SEVERAL PLANETS AND THEIR SATELLITES AS PARTS OF THE SOLAR DOMAIN.

The especial object of a physical description of the Universe is, as I have already remarked, the assemblage, both in the sidereal and telluric range of phenomena, of all the most important numerical results resting on adequate and accurate investigation up to the present time—viz. the middle of the nineteenth century. The forms and the movements of the physical Universe are here depicted as Created, Existing, Measured. Neither the bases on which the obtained numerical results repose,—nor the cosmogonic conjectures which, in the varying states of mechanical and physical knowledge, have arisen in different ages respecting the mode of formation,—nor questions relating to the mysterious act of Creation itself,—belong, in a strict sense, to the domain of these empirical deductions (Kosmos, Bd. i. S. 29—31, 63, and 87; Eng. ed p. 30—33, 57, and 75).

### *The Sun.*

I have stated in the preceding pages (Bd. iii. S. 378—405; Eng. ed. p. 267—295) both the numerical results and the views now prevailing respecting the physical constitution of the central body of our system. It only remains to give, from observations made since those pages were written, some

additional remarks on the red or roseate appearances referred to in pages 278—280 of the English translation. The important phenomena presented by the solar eclipse of the 28th July, 1851, which was total in the East of Europe, have added fresh force to the opinion expressed by Arago in 1842, that the red mountain- or cloud-like projections on the margin of the darkened solar disk belong to the gaseous outermost envelope of the Sun (545). These projections were gradually *uncovered* by the receding west limb of the Moon as that body continued its course to the eastward (Annuaire du Bureau des Longitudes pour 1852, p. 457), and, on the other hand, disappeared on the opposite side as they were gradually *covered* by the advancing eastern limb of the Moon.

The intensity of the light of these marginal projections was so considerable that it was possible to recognise them in the telescope through thin veiling clouds, and even with the naked eye within the corona.

The shape of some of these mostly ruby- or peach-red forms was seen to undergo rapid and sensible alteration during the short continuance of the total eclipse: one of the projections appeared bent at the top, and showed itself to many observers as an overhanging column of smoke in proximity to a freely suspended detached cloud (546). The elevation of the projections was estimated for the most part at from 1′ to 2′: in one case it seems to have been even greater. Besides these pointed elevations, of which from three to five were counted, there were also seen long, narrow, crimson-coloured bands, often dentated at the edges, appearing as if resting against the margin of the Moon (547).

The part of the Moon's limb which was not projected on the Sun's disk (548) was again most distinctly seen.

Near the part of the Sun's margin where the largest overhanging red gibbosity appeared, a group of solar spots was visible,—situated, however, a few minutes distant from the margin. On the opposite side, not far from the faint easternmost marginal projection, there was also a solar spot near the Sun's limb. The actual distances, however, implied by the few minutes of space on the Sun's disk here spoken of, would oppose our assuming that the funnel-shaped openings or depressions indicated by the spots furnished the matter for these red gaseous exhalations; but since the entire surface of the Sun, when viewed with strong magnifying powers, shows visible punctures or pores, there is the greatest probability in favour of the opinion, that the same exhalations of vapour or gas which, in ascending from the body of the Sun, produce the funnel-shaped openings seen by us as solar spots ([549]), issue forth either through these openings or through the pores, and being illuminated by the photosphere, present to our view variously-shaped roseate clouds or columns of vapour in the third or outermost solar envelope.

## *Mercury.*

If we remember how much, from the earliest times, the Egyptians ([550]) were occupied with the planet Mercury (Set—Horus), and the Indians with their Budha ([551]),—how, under the clear sky of Western Arabia, the star-worship of the tribe of the Asedites ([552]) was directed exclusively to Mercury,—and that Ptolemy, in the 9th book of the Almagest, was even able to avail himself of fourteen observations of that planet, extending back to 261 years before our era, and belonging in part to the Chaldeans

([553]),—we shall be surprised that Copernicus, who lived to attain his 70th year, should have had to complain on his death-bed that, much as he had tried, he had never seen Mercury. Nevertheless, the Greeks designated this planet, and justly so, "the strongly sparkling" (στιλβων) ([554]), on account of its occasional intense light. Like Venus, it presents to us phases or varying forms in its illuminated portion; and appears to us sometimes as a morning, and sometimes as an evening star.

Mercury, at its mean solar distance, is little more than 8 millions of German, or 32 millions English, geographical miles from the Sun, being exactly 0·3870938 parts of the Earth's mean distance from the Sun. From the great excentricity of its orbit (0·2056163), the distance of Mercury from the Sun is, in perihelion, 6¼, and in aphelion 10 millions of German geographical miles (25 and 40 millions English). It completes its revolution round the Sun in 87 mean terrestrial days, 23 hours, 15 minutes, and 46 seconds. By the somewhat uncertain observations of the shape of the southern horn of the sickle, and by noticing a dark streak which was blackest towards the east, Schröter and Harding estimated its time of rotation at 24 hours 5 minutes.

According to Bessel's determinations made on the occasion of the transit of Mercury on the 5th of May, 1832, its true diameter is 671 German, or 2684 English geographical miles ([555])—*i. e.* 0·391 parts of the Earth's diameter.

The mass of Mercury was assigned by Lagrange from very hazardous assumptions respecting the reciprocities of ratios of densities and distances. Encke's comet of short period first afforded a means of correcting this

important element. Encke has determined the mass of Mercury at $\frac{1}{4865751}$ of the Sun's mass, and about $\frac{1}{13 \cdot 7}$ of that of the Earth. Laplace, in accordance with Lagrange, had made $\frac{1}{2025810}$, but the true mass is only about $\frac{5}{12}$ths of that quantity. This correction refutes at the same time the previous hypothetical statement of the rapid increase of planetary density with increasing proximity to the Sun. If, with Hansen, we take the volume of Mercury at $\frac{6}{100}$ths of that of the Earth, the resulting density of Mercury, as compared to that of the Earth, is only as 1·22 : 1. "These determinations," adds my friend, their author, "are only to be considered as first attempts, which, however, approximate much more nearly to the truth than Laplace's assumption." Ten years ago, the density of Mercury was still assumed to be almost three times greater than that of the Earth (2·56 or 2·94), that of the Earth being = 1·00.

## *Venus.*

The mean distance of Venus from the Sun is 0·7233317 in parts of the Earth's solar distance, or 15 German or 60 English millions of geographical miles. The sidereal or true period of revolution of Venus is 224 days, 16 hours, 49 minutes, 7 seconds. No other planet approaches so near to the Earth as does Venus: it may approach us within 5¼ German, or 21 English, millions of geographical miles; but it may also be as remote as 36 German, or 144 English, millions of geographical miles: and hence the great variability of its apparent diameter, but which by no means determines solely the intensity of its brightness (557). The excentricity of Venus's orbit is only 0·00686182, expressed

in parts of the semi-major axis. The diameter of this planet is 1694 German, or 6776 English, geographical miles; its mass $\frac{1}{401839}$; its volume 0·957, and its density 0·94, as compared to the Earth.

Of the transits of the two inferior planets, first announced by Kepler in his Rudolphine Tables, it is that of Venus which, by the aid it affords towards the determination of the Sun's parallax and the distance of the Earth from the Sun thence derived, is most important in its bearings on the theory of the entire planetary system. According to Encke's complete investigation of the transit of Venus which happened in 1769, the Sun's parallax is 8″·57116 (Berliner Jahrbuch für 1852, S. 323). On the proposal of a distinguished mathematician—Professor Gerling, of Marburg—since 1849, a new investigation respecting the Sun's parallax has been undertaken by the orders of the Government of the United States of North America. It is designed to obtain the parallax by means of observations of the planet Venus near its eastern and western elongation, as well as by micrometric measurements of the differences in Right Ascension and Declination of well-determined fixed stars, made at places on the Earth's surface differing considerably in latitude and longitude (Schum. Astr. Nachr. No. 599, S. 363; and No. 613, S. 193). The astronomical expedition charged with the prosecution of this undertaking, and which is commanded by a highly-informed officer—Lieutenant Gilliss, of the United States Navy—has proceeded to Santiago de Chile.

The rotation of Venus upon its axis was long the subject of many doubts. Dominique Cassini, in 1669, and Jacques Cassini, in 1732, found 23 hours 20 minutes as its period;

while Bianchini (558) at Rome, in 1726, assumed the slow rotation of $24\frac{1}{3}$ days. The more exact observations of De Vico, in the years 1840—42, have given from the mean of a great number of "spots of Venus," 23 hours, 21 minutes, 21·93 seconds.

These spots, which appear on the boundary dividing the illuminated from the shaded portion of the planet when Venus appears as a bow, are seen only rarely, and are faint and for the most part variable; so that both the Herschels, father and son, have believed them to belong, not to the solid surface of the planet, but more probably to an atmosphere surrounding it (559). The variable shape of the horns of the bow, especially of the southern, has been used by La Hire, Schröter, and Mädler, partly for estimating the heights of the mountains, and partly and more particularly for determining the rotation. The phenomena are not such as to require for their explanation such elevations as were assumed by Schröter at Lilienthal—of 5 German, or 20 English, geographical miles; but, on the contrary, only such altitudes as the mountains of our own globe present in both continents (560). In the little that we know of the aspect of the surfaces or of the physical constitution of the two planets nearest to the Sun (Mercury and Venus), an exceedingly curious enigma is presented by the appearance of an ash-coloured light, or an evolution of light not derived from any other body, which has been occasionally observed on the dark part of Venus by Christian Mayer, William Herschel (561), and Harding. The great distance renders it unlikely that the reflected light of the Earth should be the cause in Venus as it is in the Moon.

No compression at the poles has yet been observed

in either of the two inferior planets — Mercury or Venus.

## *Earth.*

The mean distance of the Earth from the Sun is 12032 times greater than the Earth's diameter—therefore 20682000 German, or 82728000 English, geographical miles, this quantity being considered uncertain to about 90000 German, or 360000 English, geographical miles, or $\frac{1}{230}$th of its amount. The time of the sidereal revolution of the Earth round the Sun is $365^d. 6^h. 9^m. 10^s.7496$. The excentricity of the Earth's orbit amounts to 0·01679226, its mass is $\frac{1}{359551}$, and its density in proportion to water is as 5·44 to 1. Bessel's investigation of ten measurements of degrees gave the terrestrial ellipticity $\frac{1}{299 \cdot 153}$; the length of a German geographical mile of 15 to a degree at the equator 3807·23 toises; and the equatorial and polar diameters respectively 1718·9 and 1713·1 such miles, or 6875·6 and 6852·4 English geographical miles (Kosmos, Bd. i. S. 421, Anm. 100; Eng. ed. p. xlii. Note 130). I confine myself here to numerical data of figure and motion; all that relates to the physical constitution of the Earth is reserved for the last—*i. e.* the telluric portion of the Cosmos.

## *The Earth's Satellite.*

The mean distance of the Moon from the Earth is 51800 German, or 207200 English, geographical miles; its sidereal period of revolution 27 days, 7 hours, 43 minutes, and 11·5 seconds; the excentricity of its orbit 0·0548442; its diameter 454 German, or 1816 English, geographical miles,

being nearly $\frac{1}{4}$ of the Earth's diameter; its volume $\frac{1}{54}$th of that of the Earth; its mass, according to Lindenau, $\frac{1}{87.73}$ (according to Peters and Schidloffsky, $\frac{1}{81}$) of the mass of the Earth; and its density 0·619, or almost $\frac{3}{5}$ths the density of the Earth. The Moon has no sensible flattening at the poles, but has an extremely small elongation or swelling towards the Earth (the amount of which is determined by theory). The rotation of the Moon round its axis is performed (as is probably the case with all satellites in reference to their respective primary planets) in exactly the same time as that in which it completes its revolution round the Earth.

The solar light reflected from the surface of the Moon is in every zone fainter than the solar light reflected in the daytime from a white cloud. When taking lunar distances from the Sun for determinations of geographical longitude, it is not unfrequently found difficult to distinguish the Moon's disk among the more intensely illuminated cumuli. On mountains between thirteen and seventeen thousand feet high, where, in the clearer mountain air, only light, feathery cirrous clouds are to be seen, I found it much easier to distinguish the Moon's disk, both because cirrus from its slighter texture reflects less of the Sun's light, and the light of the Moon loses less in passing through thin atmospheric strata. The ratio of the intensity of the Sun's light to that of the full moon deserves a fresh investigation, as Bouguer's generally received determination ($\frac{1}{300000}$) differs so strikingly from the indeed more improbable one of Wollaston ($\frac{1}{800000}$) (562).

The yellow light of the Moon appears white by day, because the strata of air through which we see it being blue, present the complementary colour to yellow (563). According-

ing to the many and various observations made by Arago with his polariscope, the light of the Moon contains polarised light, which is most distinctly traceable during the first quarter of the Moon and in the grey spots on its surface: for example, in the large, dark, sometimes somewhat greenish, wall-surrounded plain called the Mare Crisium. Such plains are mostly traversed by long low ridges of hills, offering those angles of inclination of the surface which are required for the polarisation of the reflected solar light. The dark tone of colour of the adjacent parts seems, moreover, to render the phenomenon still more sensible by contrast. As regards the shining central mountain of the group called Aristarchus, on which observers have repeatedly imagined that they saw volcanic action taking place, it showed no stronger polarisation of light than did other parts of the Moon's surface. In the full moon no mixture of polarised light was perceived; but during a total lunar eclipse (31st May, 1848) Arago remarked undoubted signs of polarisation in the reddened disk of the Moon,—a phenomenon of which we shall have occasion to speak presently (Comptes rendus, T. xviii. p. 1119).

That the light of the Moon does produce heat is (like so many others due to my celebrated friend Melloni) among the most important and most surprising discoveries of our century. After many unsuccessful attempts, from La Hire to those of the acute Forbes ([564]), Melloni, by means of a lens (lentille à échelons) of three feet diameter, made for the Meteorological Institution on the Cone of Mount Vesuvius, succeeded, in different phases of the Moon, in observing most satisfactory indications of an elevation of temperature. Mosotti, Lavagna, and Belli, Professors of the Universities

of Pisa and Pavia, witnessed these experiments, the results of which varied according to the Moon's age and altitude. To what amount, expressed in fractional parts of the centigrade thermometer, the increase of temperature produced in Melloni's thermoscopic pile corresponded, had not then (in the summer of 1846) been examined (565).

The ashy grey light seen on the Moon's disk, when for some days before and after the new moon the part illuminated by the Sun is only a narrow bow, is earthlight on the Moon—"the reflection of a reflection." The less the Moon appears illuminated as viewed from the Earth, the more illuminated is the Earth as viewed from the Moon. But the earthlight received on the Moon is $13\frac{1}{2}$ times stronger than the moonlight received on the Earth, and is bright enough to be perceived by us on a second reflection. In this faint light the telescope can distinguish both the larger spots, and also bright shining points—mountain-summits in the lunar landscapes; and, even when more than half the Moon's disk reflects to us the full illumination of the Sun, a faint grey light can still be seen on the remaining portion by the aid of the telescope (566). These phenomena are particularly striking when viewed from the high mountain plateaus of Quito and Mexico. Since Lambert's and Schröter's writings, the opinion has prevailed, that the very various degrees of intensity of the grey light of the Moon at different times proceed from the stronger or fainter return of the solar light from the surface of the Earth, according as this is reflected from connected continental masses full of sandy or rocky deserts, grassy steppes, and tropical forests, or from extensive oceanic surfaces. Lambert, on the 14th of February, 1774, made,

with a comet-finder having a very light field, the remarkable observation of a change of the grey or ashy light of the Moon into an olive-green colour, verging somewhat towards yellow. The moon, which then stood vertically over the Atlantic Ocean, received on its nocturnal side the green earthlight sent to it in a cloudless sky from the forest-covered regions of South America ([567]).

The meteorological state of our atmosphere modifies the intensity of this earthlight, which has to traverse the double path from the Earth to the Moon, and from the Moon again to our eyes. "Thus," as Arago has remarked ([568]), "when at some future day better photometric instruments shall be employed, we shall be able to read, as it were, in the Moon the *mean state* of transparency of our atmosphere." The first correct explanation of the nature of the ashy light of the Moon was given in a letter written by Kepler (ad Vitellionem Paralipomena quibus Astronomiæ pars optica traditur, 1604, p. 254) to his highly venerated former instructor Mästlin, and put forward by the latter in 1596, on the occasion of the thesis publicly defended at Tübingen. Galileo (in the Sidereus Nuncius, p. 26) spoke of the reflected earthlight as of a thing which he had himself discovered several years before; but in reality, a hundred years prior to Kepler and Galileo, the true explanation of the earthlight visible to us on the Moon had not escaped the all-embracing genius of Leonardo di Vinci. His long-forgotten manuscripts have afforded the proof of this ([569]).

In total lunar eclipses it happens in some exceedingly rare cases that the Moon disappears wholly: it did so, according to Kepler's earliest observation ([570]), on the 9th of

December, 1601; and in more recent times, on the 10th of June, 1816, in London, when it could not be discerned even with telescopes. A peculiar, not sufficiently explained, state of the several strata of the atmosphere in regard to transparency must be the cause of this equally rare and curious phenomenon. Hevelius remarks expressly, that, in a total eclipse on the 25th of April, 1642, the sky was covered with sparkling stars, the air being perfectly clear, and yet, with the very various magnifying powers which he employed, the Moon's disk continued without a trace of visibility. In other also very rare cases, only some portions of the Moon are faintly visible. In ordinary cases the disk appears, during a total eclipse, of a reddish hue, the colour being, indeed, of the most various degrees of intensity, passing even, when the Moon is far removed from the Earth, into a fiery glowing red. Whilst, more than half a century ago (29th of March, 1801), I was lying at anchor off the Island of Baru, not far from Cartagena de Indias, and observing a total lunar eclipse, I was exceedingly struck by seeing how much brighter the reddened disk of the Moon appears in the sky of the tropics than in my northern native land (571). The whole phenomenon is known to be the result of the refraction of the rays, since, as Kepler very correctly expresses it (Paralip. Astron. pars optica, p. 893), the Sun's rays are inflected in their passage through the Earth's atmosphere (572), and thrown into the cone of shadow. The disk, whether it be of paler or darker red, is never uniform in colour throughout. Some parts always show themselves of deeper tint than others, and the change of colour takes place progressively. The Greeks had a peculiar theory

respecting the colours which the darkened moon should exhibit, according to the different hours at which the eclipse commences ([573]).

In the long-continued controversy respecting the probability or improbability of an atmospheric envelope to the Moon, exact observations of occultations of stars have shown that no refraction takes place at the Moon's edge; and Schröter's assumptions ([574]) of a lunar atmosphere and lunar twilight are thus refuted. The comparison of the two values which may be derived for the Moon's semi-diameter, on the one hand from direct measurement, and on the other from the duration of the occultation of a fixed star, (*i. e.* the length of time which the Moon takes to pass over the star), shows that, at the moment when the Moon's limb comes in contact with the star, the starlight is not deflected from its rectilinear course by an amount sensible to our eyes. If there were refraction at the margin of the Moon's disk, the second determination of the semi-diameter must come out less than the first by twice the amount of such refraction; whereas it has been found, by repeated trials, that the two determinations agree so nearly that it has not been possible to find any decided difference between them ([575]). The immersion or disappearance of a star behind the Moon, which can be observed with particular precision on the dark margin, takes place suddenly, and without any gradual diminution of the star's brightness; and the same is the case with the emersion or reappearance of a star. The few exceptions which have been remarked may have had for their cause accidental changes in our own atmosphere.

If, then, the Moon is without any gaseous envelope, the

entire absence of any diffused light must cause the heavenly bodies, as seen from thence, to appear projected against a sky *almost black* in the daytime ([576]). No undulation of air can there convey sound, song, or speech. The Moon, to our imagination which loves to soar into regions inaccessible to full research, is a desert where silence reigns unbroken.

The phenomenon which is sometimes remarked in occultations of stars by the Moon, of a pausing or "cleaving" of the star to the Moon's limb or margin ([577]), cannot well be regarded as a consequence of the "irradiation," which, from the great difference in the intensity of their light, causes the part of the Moon illuminated directly by the Sun, when only a narrow bow, to appear to the eye as if it encompassed the remaining dark portion. In a total lunar eclipse Arago saw most distinctly a star cleave during the conjunction to the dimly-illuminated red disk of the Moon. Whether the phenomenon here alluded to is to be regarded as the effect of physiological causes ([578]), or of aberration arising from the refrangibility and sphericity of the eye ([579]), is still a subject of discussion between Arago and Plateau. The cases in which it is affirmed that in an occultation a disappearance and a reappearance, and then again a disappearance, have been seen, may very well indicate an outline of the moon accidentally deformed by mountain precipices and deep chasms.

The great differences visible in the reflected light in different parts of the illuminated lunar disk, and especially the irregularity of the line which separates the illuminated from the unilluminated portion of the disk in phases intermediate between new and full moon, gave occasion in very early times to the formation of intelligent views respecting

the inequalities of the surface of our satellite. Plutarch, in his small but very remarkable treatise on "the Face in the Moon," says expressly, that in the spots which we see we may surmise the existence partly of deep clefts and valleys, and partly of mountain summits "which cast long shadows like Mount Athos, whose shadow reaches to Lemnos" ([580]). The spots cover about two-fifths of the whole disk. Under favourable circumstances of the Moon's position and the state of the atmosphere, it is quite possible to distinguish with the naked eye the ridges of the Apennines, the dark wall-surrounded plain of Grimaldi, the detached Mare Crisium, and Tycho, with the mountain-ridges and craters crowded around it ([581]). It has been said, not without probability, that it was in particular the aspect of the Apennine chain which occasioned the Greeks to regard the spots in the Moon as mountains, and, as has just been remarked, to refer in connection therewith to the shadow of Mount Athos, which, at the solstice, reached to the Brazen Cow in Lemnos. Another very fanciful opinion respecting the spots on the Moon was that of Agesianax, contested by Plutarch, according to which the Moon's disk was supposed to reflect back to us catoptrically, as in a mirror, the forms and outlines of our continents and of the "outer (Atlantic) Sea." An opinion quite similar to this seems to have continued as a popular belief in Western Asia to the present day ([582]).

By the careful employment of large telescopes we have gradually succeeded in obtaining a topographical representation of the Moon based on actual observation; and, as in Opposition, the whole of one side of the Earth's satellite presents itself to our examination, we know more of the

general and simply superficial configuration of the mountain-groups of the Moon, than we do of the orography of the half of the Earth's surface, which comprises the interior of Asia and Africa. Generally speaking, we regard the darker parts of the Moon's disk as the plains and depressions, and the brighter parts, which reflect most solar light, as the more elevated and mountainous parts. Kepler's old denomination of sea and land has long been given up; and even Hevelius, notwithstanding the similar nomenclature to which he gave currency, already doubted the correctness of such an interpretation, and the truth of the contrast it implied. The circumstance that, on careful examination with very different illumination, all parts of the so-called lunar "seas" have shown themselves completely uneven, and because polyhedric, or full of angles, therefore giving much polarised light, has been adduced as being particularly at variance with the supposition of the presence of liquid surfaces. Arago has noticed, however, in regard to this reasoning, that some of these surfaces might, notwithstanding their inequalities, belong to a not over-deep sea-bottom covered with water; since in our own planet we find that the uneven rocky bed of the ocean can be distinctly seen on looking down from a great height, because the intensity of the light which ascends from below surpasses that of the light which is radiated from the surface of the sea (Annuaire du Bureau des Longitudes pour 1836, p. 339—343). In the forthcoming work of my friend—his "Astronomy and Photometry"—the probable absence of water on the surface of our satellite will be deduced from other optical reasons which we do not enter upon here. Of the low "plains," the largest are in the northern and eastern parts of the Moon's disk. Among

them, the not very definitely bounded Oceanus Procellarum has the greatest extent (90000 German geographical square miles). In connection with the Mare Imbrium (16000 German square miles), the Mare Nubium, and in some degree with the Mare Humorum, and inclosing insular highlands (the Riphæan Mountains, Kepler, Copernicus, and the Carpathians), the eastern darker portion of the Moon's surface forms the most decided contrast with the more brightly beaming south-western region, in which mountain is crowded against mountain ([583]). In the north-western region there are two more detached and isolated basins—the Mare Crisium (3000 German geographical square miles), and the Mare Tranquillitatis (5800 such miles).

The colour of these so-called seas is not always grey. The Mare Crisium has a grey tint mixed with dark green, and the Mare Serenitatis and Mare Humorum are likewise green. Near the Hercynian Mountains, the isolated part inclosed within the circumvallation called Lichtenberg, has, on the other hand, a pale-red tint; and so, also, has Palus Somnii. Annular depressions without central mountains have most often a dark steel-grey tint verging towards bluish. The causes of these different tints of colour in the rocky or other less coherent substances forming the surface, are exceedingly enigmatical.

A great wall-surrounded plain called Plato (by Hevelius, Lacus niger major), on the north of the "Alps," and still more, Grimaldi in the equatorial region, and Endymion, near the north-western margin, are the three darkest places in the whole lunar disk; and the brightest of all is Aristarchus, of which, when it is on the portion of the Moon not

otherwise directly illuminated by the Sun, the points sometimes shine almost like stars. All these alternations of light and shade affect an iodized plate, and, with strong magnifying powers, are represented on Daguerreotypes with admirable fidelity. I possess myself such a light-picture of the Moon, of two inches' diameter, in which the so-called seas and annular mountains are clearly recognised: it was prepared by a distinguished artist, Mr. Whipple, of Boston.

If, in some of the "seas" (Crisium, Serenitatis, and Humorum) we are struck with the circular form, we find the same repeated still more frequently, and indeed almost universally, on the mountainous part of the Moon's disk, particularly in the configuration of the enormous masses of mountain which fill the southern hemisphere from the pole nearly to the equator, where the mass terminates in a point. Many of the annular mountains and wall-surrounded plains (the largest containing, according to Lohrmann, above a thousand square miles) form connected series running in the direction of meridians, between 5° and 40° South latitude ([584]). The northern polar region contains comparatively a very small proportion of these crowded mountain rings; but between 20° and 50° North latitude, near the western margin of the northern half of the Moon's disk, they form a connected group. The Mare Frigoris approaches to within a few degrees of the North Pole itself; and thus this part, like the whole of the level north-eastern space, inclosing only a small number of isolated annular mountains, (Plato, Mairan, Aristarchus, Copernicus, and Kepler), presents a great contrast to the more mountainous Southern Pole. Near the latter, lofty summits shine, in the

strictest sense of the words, throughout whole lunations in "perpetual light;" they are truly "islands of light," and can be recognised with very low magnifying powers ([585]).

As exceptions to the generally prevailing lunar type of circular and annular forms, we find, almost in the middle of the northern half of the Moon's disk, some true mountain-chains (Apennines, Caucasus, and Alps). They range nearly from south to north, through almost 32° of latitude, in the form of a very flattened bow a little curved towards the west. Here we see countless mountain ridges, and some exceedingly pointed summits crowded together. Only a few annular mountains and crater-like depressions (Conon, Hadley, and Calippus) are interspersed, and the whole resembles more nearly the conformation of our terrestrial mountain-chains. The lunar Alps, which are inferior in elevation to the lunar Caucasus and Apennines, present a remarkably broad cross valley, which intersects the chain from S.E. to N.W. It is surrounded by summits which surpass in altitude the Peak of Teneriffe.

A comparison between the elevations on the Moon and on the Earth, viewed relatively to the diameters of the two bodies, gives the remarkable result, that while the satellite is four times less than the planet, its highest summits are only 600 toises (3837 Eng. feet) lower than the highest summits of the Earth; so that the lunar mountains are $\frac{1}{454}$ of the Moon's diameter, and the terrestrial mountains $\frac{1}{1481}$ of that of the Earth. Of the 1095 elevations which have been measured on the Moon, I find 39 which are higher than Mont Blanc, and 6 above 18000 Paris feet (19184 English). The measurements are made either by determining the distance, reckoned from the limit

between the bright and dark parts of the Moon, of the illuminated mountain summits appearing as points of light on the dark part, or by the length of the shadows. The first method was that employed by Galileo, as is evident from his letter to Pater Grienberger on the Montuosità della Luna.

According to Mädler's careful determinations made by measuring the lengths of the shadows, the culminating points of the Moon near the southern margin, very near to the pole, are, in descending series — Dörfel and Leibnitz, 3800 toises (24300 English feet); the annular mountain, Newton, where a part of the deep excavation is never shone upon either by the light of the Sun or that of the Earth, 3569 toises (22822 Eng. feet); Casatus, east of Newton, 3569 toises (22822 Eng. feet); Calippus, in the Caucasus chain, 3190 toises (20400 Eng. feet); and the Apennines between 2800 and 3000 toises (17900 and 19180 Eng. feet). It must here be remarked, that, from the total want of a general zero line of level (a plane equidistant from the centre of the body, like the surface of the sea in our own planet), the absolute heights are not strictly intercomparable: the six numerical results given above express, properly speaking, only the differences between the summits and the nearest plains or low points ([587]). It is certainly a striking circumstance that Galileo attributed to the highest mountains in the Moon an elevation of "incirca miglia quatro"—about four geographical miles of 60 to the terrestrial equatorial degree, or 3800 toises, the height actually assigned above to the lunar mountains Dörfel and Leibnitz. According to the hypsometric knowledge possessed by him, Galileo estimated this height as superior to that of any terrestrial mountain.

An exceedingly curious and enigmatical phænomenon in the surface of our satellite, and one which seems to belong to an optical effect ot luminous reflection, and not to a hypsometric difference, is presented by the narrow streaks of light which disappear in an oblique illumination, and, contrary to the lunar spots, are most visible in the full moon. These streaks form radiating systems. They are not lines of mountains, they do not cast any shadows, and they run in uniform intensity of light from the plains to elevations twelve or thirteen thousand feet and upwards. The most extensive of these radiating systems is that which proceeds from Tycho, and in which more than a hundred streaks of light, mostly of several miles in breadth, can be distinguished. Similar systems, surrounding Mounts Aristarchus, Kepler, Copernicus, and the Carpathians, are almost all connected with each other. It is difficult to conjecture from analogy or induction what is the particular alteration of surface which occasions these bright shining bands, radiating from particular annular mountains.

The circular type—which we have already noticed as prevailing almost everywhere upon the Moon's surface, (in the wall-surrounded plains which often inclose central mountains, and in the great annular mountains and their craters, of which 22 have been counted in Bayer, and 33 in Albategnius, crowded closely together)—gave occasion to the profound thinker, Robert Hooke, to seek for the cause of this phenomenon in the reaction of the interior of the Moon against its exterior; or, as he expressed it, as "the effect of subterranean fires and elastic vapours breaking forth even to ebullition, sending up to the surface bubbles or blisters." Experiments by boiling thick calcareous solu-

tions appeared to him to confirm his view; and the circumvallations with their central mountains were compared by him to "the forms of Etna, the Peak of Teneriffe, Hecla, and the volcanoes of Mexico described by Gage" ([588]).

Galileo, as he himself relates, had been reminded, by a circular wall-surrounded plain in the Moon (probably from its magnitude), of the configuration of entire countries surrounded by mountains. I have found a passage ([589]) in which he compares these lunar forms with the great closed basin of Bohemia. In fact, several of the circular wall-surrounded plains of the Moon are but little less extensive, for they have diameters of from 25 to 30 German geographical miles (100 to 120 English) ([590]). On the other hand, the proper annular or ring mountains scarcely exceed 2 or 3 German (8 to 12 Eng.) geographical miles in diameter. Conon in the Apennines is 8 English geographical miles across; and a crater belonging to the brightly shining district of Aristarchus has even a diameter of only 400 toises (or about 450 yards), just half the breadth of the crater of Ruchu-Pichincha in the mountains of Quito, measured trigonometrically by myself.

As we are here dwelling on comparisons with well-known terrestrial phænomena and dimensions, it is the proper place to remark that in this view the greater part of the wall-surrounded plains and annular mountains of the Moon may be most directly regarded as "craters of elevation, without continuous phænomena of eruption," in the sense of Leopold von Buch's geological hypothesis. What, according to the European standard, is called large on the terrestrial surface —the craters of elevation of Rocca Monfina, Palma, Teneriffe, and Santorin—are indeed altogether inconsiderable as

compared with Ptolemy, Hipparchus, and many other lunar forms. In breadth, Palma is only 3800 toises (24300 Eng. feet); Santorin, according to Captain Graves's recent determination, 5200 toises (33250 Eng. feet); and Teneriffe, at the utmost, 7600 toises (48600 Eng. feet), or only $\frac{1}{8}$th or $\frac{1}{6}$th of the breadths of the two above-named lunar craters. The small craters of the Peak of Teneriffe and Vesuvius (little more than three or four hundred feet in diameter) would hardly be discernible through telescopes. In by far the greater number of cases the annular mountains are destitute of any central mount; and, where such exist, they are described as dome-shaped or flattened (as Hevelius and Macrobius), not as cones of eruption with openings ([591]). I here mention, solely on account of the historical interest which may attach to them, the accounts given of the burning volcanoes supposed to have been seen on the dark side of the Moon on the 4th of May, 1783, and the luminous appearances in Plato observed by Bianchini (16th Aug. 1725) and by Short (22d April, 1751). The causes of the illusion have long since been ascertained. They belong to the more vivid earth-light reflected by particular portions of the surface of our planet upon the dark side of the Moon ([592]).

It has been remarked, and doubtless with much reason, that, from the absence of water on the moon—(the "rills," which are very narrow, and in most cases rectilinear depressions ([593]), are not rivers)—we may imagine its surface to bear a general resemblance to that of the Earth in its primitive or more ancient condition, before the deposit of shelly sedimentary strata, or the formation, transportation, and distribution of alluvium by the continued action

of tides and currents. (The absence of seas in the Moon forbids the supposition of tides raised by the Sun and Earth.) The most that we can suppose would be small deposits of detritus resulting from friction. In our mountain-chains upheaved over fissures, we are also gradually beginning to recognise here and there partial groupings of elevations, forming, as it were, egg-shaped basins. How entirely different would the Earth's surface appear to us, if we saw it stripped of the sedimentary and tertiary formations, and of all alluvial deposits!

The Moon, far more than all the other planetary bodies, diversifies and enlivens the aspect of the firmament in every zone by its varying phases and more rapid change of position relatively to the fixed stars; while man, and even the beasts of the forest ([594]) (especially in the primeval forests of the torrid zone), rejoice in its mild lustre. By the attracting force which it exerts in conjunction with the Sun it communicates motion to our seas, and, by the periodical raising of their surfaces and the eroding action of the tides, gradually modifies the outlines of our coasts, impedes or favours man's labours, and furnishes the greater part of the materials of which sandstones and conglomerates are composed, these last being again covered in their turn by the loose rounded particles which form alluvium ([595]). Thus the Moon, as one of the "sources of movement" on the terrestrial surface, influences continually the geognostic features of our planet.

The incontestible action ([596]) of our satellite on atmospheric pressure, aqueous precipitations, and the dispersion of clouds, will be treated of in the latter and purely telluric portion of the Cosmos.

*Mars.*

The diameter of this planet is 892 German, or 3568 English geographical miles, (being only 0·519 of the Earth's diameter, notwithstanding its considerably greater solar distance). The excentricity of its orbit is 0·0932168; being, next to that of Mercury, the greatest among the old planets. This circumstance, together with its proximity to the Earth, rendered it the best adapted to lead to Kepler's great discovery of the elliptic orbits of the planets. The rotation of Mars ([597]) is, according to Mädler and Wilhelm Beer, 24 hours, 37 minutes, and 23 seconds. The sidereal period of revolution round the Sun is 1 year, 321 days, 17 hours, 30 minutes, 41 seconds. The inclination of the orbit of Mars to the terrestrial Equator is 24° 44′ 24″; the mass of the planet $\frac{1}{2680337}$; and its density, in comparison with that of the Earth, 0·958. As the great approximation of Encke's comet was made use of for investigating the mass of Mercury, so the mass of Mars will some day be ascertained with greater accuracy by the perturbations which it may cause in the movements of De Vico's comet.

The compression of the planet Mars at its poles, which, singularly enough, was always doubted by the great astronomer of Königsberg, was first recognised by William Herschel in 1784. In respect to the amount of the ellipticity, however, uncertainty long prevailed. William Herschel gave it as $\frac{1}{16}$; according to Arago's more exact measurement ([598]) with a prismatic telescope of Rochon, it would be much less: in 1824 he found it as 189 : 194, or $\frac{1}{38 \cdot 8}$; and, by a later measurement in 1847, it was found $\frac{1}{32}$. Arago, however, is inclined to believe that the com-

pression is somewhat greater than either of the two last-named quantities.

If the study of the surface of the Moon reminds us of many geognostical relations in the surface of our own planet, the analogies with the Earth which Mars presents are, on the other hand, entirely of a meteorological kind. On the disk of Mars (besides the dark spots, of which some are blackish, others—very few in number, however—orange ([599]), and surrounded by what are called "seas" ([600]) of the contrasted colour, green) at the two poles of the axis of rotation, or it may be at the poles of cold in their vicinity, are two white snow-bright patches ([601]). These were noticed as early as 1716 by Philip Maraldi; but their connection with climatic variations in the planet was first described by the elder Herschel in 1784, in the 74th volume of the Philosophical Transactions. The white spots become alternately larger or smaller as the pole approaches its winter or its summer. Arago has measured with his polariscope the intensity of the light of these snowy zones, and has found it twice as great as that of the light of the remainder of the disk. The "Physico-astronomical Contributions" of Mädler and Beer contain some excellent graphical representations ([603]) of the northern and southern hemispheres of Mars, in which this remarkable phænomenon, unique so far as our knowledge extends in the entire planetary system, is shown in its relations of measure, in all the variations through which it passes under the influence of the change of seasons and the powerful action of the polar summer in melting the snow. Careful observations continued for ten years have also taught us that the dark spots of Mars retain constantly both their forms and their relative positions on the planet. The periodical enlarge-

ment of the snowy districts,—being a meteorological phænomenon implying aqueous precipitations dependent, as respects their character, on changes of temperature,—and some optical phænomena presented by the dark spots when the rotation of the planet brings them to the margin of the disk, render the existence of an atmosphere of Mars more than probable.

### *The Small Planets.*

In the general considerations ([603]) on planetary bodies, we have already designated the group of the small planets (Asteroids, Planetoids, Coplanets, or telescopic or ultra-zodiacal planets) intermediate between Mars and Jupiter as a *middle group,* forming in some degree a *dividing zone,* separating the solar domain into an inner and an outer portion—the one comprising the four interior planets, Mercury, Venus, Earth, and Mars; and the other the four exterior planets, Jupiter, Saturn, Uranus, and Neptune. This middle group has a highly distinct character of its own, in the intricate or intersecting, highly inclined, and very excentric orbits of the planets of which it consists; and also in their extraordinary smallness, as the diameter even of Vesta does not appear to equal the fourth part of that of Mercury. When the first volume of Kosmos appeared in Germany in 1845, only 4 of the small planets—Ceres, Pallas, Juno, and Vesta, discovered by Piazzi, Olbers, and Harding (1st Jan. 1801 to 29th March, 1807)—were known to us. At the present moment (July 1851) the number has increased to 14, being one-third of the number of all the known planetary bodies—*i. e.* 43 primary planets and satellites.

Within the solar domain, the attention of observers was long directed to the augmentation of the members of partial systems (the moons or satellites revolving around the primary planets), and to the discovery of new planets in the remote regions beyond Saturn and Uranus. Since the accidental discovery of Ceres by Piazzi, and more especially since the systematically-planned discovery of Astræa by Hencke, as well as since the great improvement in star-maps (604) (those of the Berlin Academy contain all stars of the 9th and many of the 10th magnitude), there is opened to astronomical activity in a nearer region of the Universe, a rich and perhaps almost inexhaustible field of research. It is a distinguishing merit of the Astronomical Jahrbuch or Almanac, published in my paternal city by Encke, Director of the Berlin Astronomical Observatory, with the co-operation of Dr. Wolfers, that the Ephemerides of the increasing host of the small planets are treated in it with peculiar fulness. Hitherto the region nearest to the orbit of Mars appears the most fully occupied; but already "the breadth of the entire zone, as given by the difference between the Radii Vectores of the nearest perihelion (Victoria), and of the farthest aphelion (Hygeia), considerably exceeds the distance of Mars from the Sun" (605).

I have already noticed (606) the large amount of the excentricity of the orbits of the small planets—of which the least are those of Ceres, Egeria, and Vesta, and the greatest those of Juno, Pallas, and Iris—as well as the inclinations of the orbits to the Ecliptic, ranging from Pallas 34° 37′, and Egeria 16° 33′, to Hygeia 3° 47′. I here subjoin a tabular view of the elements of the small planets, for which I am indebted to my friend Dr. Galle.

ELEMENTS OF THE 14 SMALL PLANETS FOR THEIR TIMES OF OPPOSITION IN OR NEAR THE YEAR 1851.

| | Flora. | Victoria | Vesta. | Iris. | Metis. | Hebe. | Parthenope. | Astræa. | Egeria. | Irene. | Juno. | Ceres. | Pallas. | Hygeia. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E | 1852. March 24. | 1850. Oct. | 1851. June 9. | 1851. Oct. 1. | 1851. Feb. 8. | 1851. July 12. | 1851. Oct. 22. | 1851. April 29·5. | 1852. March 15. | 1851. July 1. | 1851. June 11·5. | 1851. Dec. 30. | 1851. Nov. 5. | 1851. Sept. 28·5. |
| L | 174° 45′ | 342° 18′ | 256° 38′ | 18° 36′ | 126° 28′ | 311° 39′ | 17° 51′ | 197° 37′ | 162° 29′ | 234° 15′ | 276° 0′ | 105° 33′ | 72° 35′ | 356° 45′ |
| $\pi$ | 32 51 | 301 57 | 250 32 | 41 22 | 71 7 | 15 17 | 317 5 | 135 43 | 118 17 | 179 10 | 54 20 | 147 59 | 121 23 | 228 2 |
| $\Omega$ | 110 21 | 235 28 | 103 22 | 259 44 | 68 29 | 138 31 | 124 59 | 141 28 | 43 18 | 86 51 | 170 55 | 80 49 | 172 45 | 287 38 |
| $i$ | 5 53 | 8 23 | 7 8 | 5 28 | 5 36 | 14 47 | 4 37 | 5 19 | 16 33 | 9 6 | 13 3 | 10 37 | 34 37 | 3 47 |
| $\mu$ | 1086″·04 | 994″·51 | 977″·90 | 963″·03 | 962″·58 | 939″·65 | 926″·22 | 857″·50 | 854″·96 | 853″·77 | 813″·88 | 770″·75 | 768″·43 | 634″·24 |
| $a$ | 2·2018 | 2·3349 | 2·3612 | 2·3855 | 2·3862 | 2·4249 | 2·4483 | 2·5774 | 2·5825 | 2·5849 | 2·6687 | 2·7673 | 2·7729 | 3·1514 |
| $e$ | 0·15679 | 0·21792 | 0·08892 | 0·23239 | 0·12229 | 0·20186 | 0·09789 | 0·18875 | 0·08627 | 0·16786 | 0·25586 | 0·07647 | 0·23956 | 0·10092 |
| U | 1193ᵈ | 1303ᵈ | 1325ᵈ | 1346ᵈ | 1346ᵈ | 1379ᵈ | 1399ᵈ | 1511ᵈ | 1516ᵈ | 1518ᵈ | 1592ᵈ | 1681ᵈ | 1687ᵈ | 2043ᵈ |

E signifies the Epoch of the mean longitude in mean Berlin time; L, the mean longitude in the orbit; $\pi$, the longitude of the perihelion; $\Omega$, the longitude of the ascending node; $i$, the inclination of the orbit to the Ecliptic; $\mu$, the mean daily sidereal motion; $a$, the semimajor axis; $e$, the excentricity in parts of the semi-axis; U, the sidereal period of revolution in days. The longitudes refer to the equinox of the epoch.

The mutual relations of the orbits of the asteroids and the combinations of the orbits have formed the subject of ingenious investigations, first (1848) by Gould ([607]), and quite recently by D'Arrest. The latter says ([608]), "it appears to testify in favour of a real or inherent connection between all the members of the entire group of the small planets, that, if we figure to ourselves the natural dimensions of their orbits as forming actual material rings, these rings are all so interlinked, that, by taking hold of any one, all the others would be lifted by or found suspended on it. If Iris, discovered by Hind in August 1847, had accidentally remained unknown to us—as doubtless is still the case with many other planetary bodies in that region—the group would consist of two separate parts:—a circumstance which must appear the more unexpected, because the zone of the solar system occupied by these planets is a wide one."

We cannot take our leave of this wonderful and numerous planetary group, without alluding, even in this fragmentary description of the several members of the solar system, to the bold views of a highly-gifted and deeply investigating astronomer, respecting the origin of the asteroids and their mutually intersecting orbits. A result derived from Gauss's calculations—that Ceres, in her ascending passage through the plane of the orbit of Pallas, comes exceedingly near the latter planet—led Olbers to conjecture, that "possibly these two planets might be fragments of a single large planet formerly occupying the wide interval between Mars and Jupiter, but since destroyed by some natural force or catastrophe; and that we might expect to discover in the same region more such fragments describing an elliptic orbit round the Sun" ([609]).

The possibility of determining by calculation, even approximately, the probable epoch of such a cosmical event, which should also be that of the origin of the small planets, is more than doubtful, seeing the complications arising from the great number of the supposed "fragments" with which we are already acquainted, the secular retrogressions of the apsides, and the movement of the nodal lines (610). Olbers marked the region of the nodal line of the orbits of Ceres and Pallas as corresponding to the northern wing of Virgo and to the constellation of Cetus. In the last-named constellation, scarcely two years later, Juno was discovered by Harding—accidentally, however—in the course of the construction of a star catalogue: in the former, after a long five years' search directed by the hypothesis, Olbers himself discovered Vesta. This is not the place for deciding whether these two results, standing by themselves, are sufficient to support the hypothesis. The cometary mists or nebulosities, in which the small planets were at first imagined to be enveloped, have disappeared before the examinations made with more perfect instruments. Olbers attributed the considerable alterations of light to which these planets were supposed to be subject, to their irregular figure as "fragments of a disrupted planet" (611).

### *Jupiter.*

Jupiter's mean distance from the Sun is 5·202767 in parts of the Earth's mean solar distance. The true mean diameter of this largest of all the planets is 19294 German, or 77176 English geographical miles,—equal, therefore, to 11·255 diameters of the Earth, and about $\frac{1}{5}$th more than

the diameter of the remoter Saturn. The sidereal revolution of Jupiter round the Sun is performed in 11 years, 314 days, 20 hours, 2 minutes, and 7 seconds. The ellipticity of its figure or compression at the poles, according to the prismatic micrometer measurements of Arago, the result of which was transferred in 1824 into the Exposition du Système du Monde (p. 38), is as 167 : 177, or $\frac{1}{17.7}$; which agrees very nearly with the later investigations (1839) of Beer and Mädler (612), who found it between $\frac{1}{18.7}$ and $\frac{1}{21.6}$. Hansen and Sir John Herschel prefer $\frac{1}{14}$. The earliest observation of Jupiter's ellipticity by Dominique Cassini was prior to the year 1666, as I have already recalled elsewhere. This circumstance has a peculiar historical interest, from the influence which, as has been acutely remarked by Sir David Brewster, it may have exercised on Newton's ideas respecting the figure of the Earth. The Principia Philosophiæ Naturalis seems to afford indications favourable to such a supposition; but the dates at which the Principia and Cassini's observations of the equatorial and polar diameters of Jupiter were respectively published, might occasion some chronological doubts on the subject (613).

As the mass of Jupiter is, next to the mass of the Sun, the most important element in the whole of our planetary system, its more exact determination in recent times by Airy (1834), by means of the perturbations of Juno and Vesta, as well as by the elongation of Jupiter's satellites, especially the 4th (614), must be regarded as one of the advances in calculating astronomy most fruitful in consequences. The effect of the corrections obtained is to augment the mass of Jupiter, and to diminish that of Mercury. The mass of

Jupiter, including his four satellites, as now known to us, is $\frac{1}{1047.879}$; whilst in 1824 Laplace still considered it $\frac{1}{1066.09}$ (615).

The rotation of Jupiter is performed, according to Airy, in $9^h$, $55^m$, $21^s \cdot 3$, mean solar time. Dominique Cassini, in 1665, had found it to be between $9^h$ $55^m$ and $9^h$ $56^m$, by means of a spot which continued to be visible on the disk of the planet for several years, and even as late as 1691, preserving always the same colour and outline (616). The spots seen on Jupiter are, in most cases, darker than the streaks or bands called Jupiter's belts. They do not, however, appear to belong to the actual surface of the planet; for it has occasionally been found that some spots, near the poles more particularly, gave a different time of rotation from that given by others in the equatorial regions. According to a very experienced observer—Heinrich Schwabe, at Dessau—the dark, more definitely bounded, spots in the two grey belts bordering the Equator have been seen for several successive years exclusively in one of the belts only, at one time in the southern, and at another in the northern belt. The process of formation of these spots is therefore subject to change in respect of place. Occasionally (it was so, according to Schwabe's observations, in November 1834) the spots of Jupiter, viewed with a magnifying power of 280 in a Fraunhofer's telescope, resemble small spots on the Sun having nuclei surrounded by penumbras; but even then their degree of blackness is less than that of the shadows of the satellites. The nucleus is probably a part of the body of the planet itself; and when the atmospheric opening through which it is seen maintains its place above the same

point, the motion of the spots gives the true time of rotation. These spots sometimes divide into two or more, also resembling in this respect the spots of the Sun, as was already recognised by Dominique Cassini in 1665.

In the equatorial zone of Jupiter there are two broad principal bands or belts of a grey or greyish-brown colour, which become paler towards the edges, and gradually fade away altogether. Their boundaries are very unequal and variable, and they are separated from each other by an intermediate quite bright equatorial streak. Towards both poles, also, the entire surface is covered with many narrower, paler, often interrupted, and even delicately-branched streaks or bands, always parallel to the Equator. "These phænomena," says Arago, "are most easily explained by the hypothesis of an atmosphere partially obscured by strata of clouds, but which, in zones adjacent to the Equator, is freed from obscuring vapours, and rendered diaphanous—probably by the effect of trade-winds. Since (as was already assumed by William Herschel, in a memoir which appeared in 1793, in the 83d volume of the Philosophical Transactions) the surface of clouds reflects a more intense light than the surface of the planet itself, so the part of the surface which we see through the clear air must appear darker than the cloudy strata which reflect much light. Therefore, grey (or dark) and bright bands alternate with each other: when the visual ray from the eye of the observer is directed at small angles obliquely towards the margin of the planet, the grey bands are seen through a more considerable and thicker mass of atmospheric strata, reflecting a greater quantity of light, and appear less dark as they recede from the centre towards the margin" ([617]).

### *Satellites of Jupiter.*

At the brilliant epoch of Galileo, the just view was already propounded, that the subordinate system of Jupiter presented, in regard to many relations of time and space, an image or picture, on a smaller scale, of the entire solar or planetary system. This view, which then spread rapidly, together with the discovery of the phases of Venus which followed soon afterwards (February 1610), contributed much to promote the more general reception of the Copernican system. The four satellites of Jupiter are the only group of satellites belonging to the outer planets which has not received any augmentation since the epoch of its first discovery (618) (by Simon Marius, on the 29th of December, 1609), a period of nearly two centuries and a half.

The following Table contains, according to Hansen, the sidereal periods of revolution of Jupiter's satellites, their mean distances expressed in semi-diameters of the central planet, and the mass of each in parts of the mass of Jupiter :—

| Satellites. | Period of revolution. | | | Distance from Jupiter. | Diameter in German geographical miles. | Mass. |
|---|---|---|---|---|---|---|
| | d. | h. | m. | | | |
| 1 | 1 | 18 | 28 | 6·049 | 529 | 0·0000173281 |
| 2 | 3 | 13 | 14 | 9 623 | 475 | 0·0000232355 |
| 3 | 7 | 3 | 43 | 15·350 | 776 | 0·0000884972 |
| 4 | 16 | 16 | 32 | 26·998 | 664 | 0·0000426591 |

If $\frac{1}{1047{\cdot}879}$ expresses the mass of Jupiter, together with

his satellites, the mass of the planet alone, without the satellites, is $\frac{1}{1048\cdot059}$, or only about $\frac{1}{6000}$th less.

Comparisons of magnitude, distance, and excentricity, with the satellites of other planets or systems, have already been given in an earlier part of the present volume (p. 338 to 340). The intensity of the light of the four satellites of Jupiter is not proportional to their volume; for, generally speaking, the 3d and the 1st, the ratio of whose magnitudes according to their diameters is as 8 : 5, appear the brightest, and the 2d, which is the smallest and densest of the satellites, is usually brighter than the larger 4th, which is considered the faintest of all. Casual or temporary fluctuations in the intensity of light of the satellites, which have also been remarked, have been ascribed sometimes to alterations in their surfaces, and sometimes to obscurations in their atmospheres (619). They, however, all appear to reflect a more intense light than the central planet When the Earth is between Jupiter and the Sun, and the satellites, therefore, in their movement from east to west, appear to enter the eastern margin of Jupiter, and, passing in front of the planet's disk, successively cover, to our eyes, different portions of it, they can be recognised in their passage, even with not very high magnifying powers, as they detach themselves "in bright" from the disk. It becomes more difficult to distinguish the satellites as they approach the centre of the planet's disk. From this early-observed phænomenon, Pound, Newton's and Bradley's friend, had already inferred that the disk of Jupiter is less bright towards the margin than at the centre. Arago believes that this statement, which has been repeated by Messier, presents difficulties which require to be solved by new and more

delicate observations. Jupiter has been seen without any of his satellites by Molyneux, in November 1681; by Sir William Herschel on the 23d of May, 1802; and lastly by Griesbach, on the 27th of September, 1843. Such a non-visibility of the satellites refers, however, only to the space external to the planet's disk, and does not oppose the theorem that all the four satellites can never be eclipsed or occulted at the same time.

### *Saturn.*

The sidereal or true period of revolution of Saturn is 29 years, 166 days, 23 hours, 16 minutes, and 32 seconds. Its mean diameter is 15507 German, or 62028 English geographical miles, equal to 9·022 diameters of the Earth. The time of rotation of Saturn, derived from observations of some dark spots (knot-like thickenings or condensations of the streaks) [620], is 10 hours, 29 minutes, 17 seconds. To this great velocity of rotation round the axis there corresponds a great compression at the poles; this compression was determined by William Herschel, in 1776, at $\frac{1}{10{\cdot}4}$. Bessel, from observations more accordant with each other and continued for three years, found, at the mean distance of the planet from the Earth, the polar diameter 15″·381, and the equatorial diameter 17″·053; giving an ellipticity or compression of $\frac{1}{10{\cdot}2}$ [621]. Saturn has also bands or belts, but less marked and somewhat broader than those of Jupiter. The most constant is a grey equatorial band: this is followed by several others, which, however, have varying forms, indicating an atmospheric origin. William Herschel found that they were not always parallel to the ring; and

they do not extend to the poles. The parts of the disk adjacent to the poles present a very remarkable phænomenon, consisting in a variation in the reflected light, dependent on the seasons of the year in Saturn. The polar regions shine more brightly in their respective winters,—a phænomenon which reminds us of the varying snowy regions of Mars,—and which did not escape the keen-sightedness of William Herschel. Whether this increased luminous intensity may arise from the temporary formation of snow and ice, or whether it may be attributed to an extraordinary accumulation of clouds, it would equally indicate effects produced by changes of temperature and the presence of an atmosphere (622).

We have already stated the mass of Saturn to be $\frac{1}{3501}$: from this amount, and from its great comparative volume (its diameter is $\frac{4}{5}$ of that of Jupiter), we infer a very small degree of density, diminishing towards the surface. If the density, (which is $\frac{76}{100}$ of the density of water), were homogeneous throughout, the compression at the poles would be still greater than it is observed to be.

This planet is surrounded in the plane of its equator by at least two detached exceedingly thin rings, situated in one and the same plane: they have a greater intensity of light than the planet itself, and the outer ring is brighter than the inner one (623). The division of what had been recognised, in 1655, by Huygens, as a single ring (624), was seen, indeed, as early as 1675 by Dominique Cassini, but was first described with exactness by William Herschel (1789—1792). Since they were first remarked by Short, finer lines or divisions in the outer ring have been repeatedly observed; but these lines or streaks have never appeared very constant.

Very recently, in the latter months of 1850, Bond, at Cambridge, U.S., on the 11th of November, with the great refractor of Merz having a 14-inch object-glass, and Dawes, at Maidstone, in England, on the 25th of November,—therefore almost simultaneously,—discovered between the second, (hitherto called the inner) ring, and the planet itself, a third very faintly illuminated, darker ring. It is divided from the second ring by a black line, and fills up a third part of the space intervening between the second ring and the planet, which has hitherto been supposed to be vacant, and through which Derham thought he had seen small stars.

The dimensions of the divided ring of Saturn have been determined by Bessel and Struve. According to Struve, the angle subtended by the external diameter of the outermost ring, at Saturn's mean distance, is 40″·09,—equal to 38300 German, or 153200 English, geographical miles;—and the angle subtended by the internal diameter of the same ring is 35″·29,—equal to 33700 German, or 134800 English, geographical miles. The external diameter of the second ring has been determined at 34″·47; and its internal diameter at 26″·67. The interval which separates the last-named ring from the surface of the planet is given by Struve at 4″·34. The entire breadth of the first and second ring is 3700 German, or 14800 English, geographical miles; the distance of the ring from the surface of Saturn is about 5000 German, or 20000 English, geographical miles; the gap which separates the first and second rings, and which is indicated by the black line of division seen by Dominique Cassini, is only 390 German, or 1560 English, geographical miles. The thickness of these rings is believed not to exceed 20 German, or 80 English, geogra-

phical miles. The mass of the rings is, according to Bessel, $\frac{1}{118}$ of the mass of Saturn. They present some ([625]) inequalities, by means of which it has been possible to observe approximately their time of rotation, which is exactly equal to that of the planet. Irregularities of form shew themselves in the "disappearances of the ring," when one of the anses usually becomes invisible sooner than the other.

The excentric position of Saturn in respect to its ring, discovered by Schwabe, at Dessau, in September 1827, is a very remarkable phænomenon. The body of the planet is a little to the west of the place which it would occupy if it were truly concentric with the surrounding ring. This observation has been confirmed by Harding, Struve ([626]), John Herschel, and South (partly by micrometric measurements). Small, apparently periodical, differences in the amount of the excentricity, which have been found from series of corresponding observations by Schwabe, Harding, and de Vico at Rome, are perhaps due to oscillations of the centre of gravity of the ring round the centre of the planet. It is a curious and striking circumstance, that so early as the end of the 17th century, an ecclesiastic of Avignon, Gallet, attempted without success to call the attention of the astronomers of that period to the excentric position of Saturn ([627]). With a density diminishing towards the surface, and so exceedingly small,—perhaps scarcely $\frac{3}{5}$ of that of water,—it is difficult to make to ourselves any representation of the molecular state, or material quality or constitution of the body of the planet; or even to decide whether this constitution should actually suppose fluidity (*i. e.* mobility of the smallest particles *inter se*), or rigidity, (according to the often adduced analogies of deal, pumice, cork, or

a solidified fluid, as ice). The astronomer of Krusenstern's expedition, Horner, terms the ring of Saturn a series of clouds; and would make the mountains of Saturn to consist of masses and vesicles of vapour ([628]). Conjectural astronomy has here a wide and legitimate field in which to exercise itself freely. Of a wholly different kind are the severer speculations, based on observation and on analytical calculus, of two distinguished American astronomers, Bond and Pierce, respecting the possibility of the "stability" of Saturn's ring ([629]). They both agree in pronouncing in favour of a state of fluidity, and also in favour of a continual variability of form and of divisibility in the outer ring. The maintenance of the general configuration is regarded by Pierce as dependent on the influence and position of the satellites, as without this dependence, even admitting inequalities in the ring, the equilibrium could not be preserved.

### *Satellites of Saturn.*

The five oldest, or longest known, satellites of Saturn, were discovered between the years 1655 and 1684 (Titan, the sixth in distance, by Huygens, and four by Cassini, viz. Japetus, the outermost of all, Rhea, Tethys, and Dione). These discoveries were followed, in 1789, by that of the two satellites nearest to the primary planet (Mimas and Enceladus), by William Herschel. Lastly, the 7th satellite, Hyperion, the last but one in point of distance, was discovered in September, 1848, almost simultaneously, by Bond, at Cambridge, U.S., and by Lassell, at Liverpool. I have before treated in this work (Kosmos, Bd. i. S. 102, and

Bd. iii. S. 463; English edit. Vol. i. p. 89, and Vol. iii. p. 340) of the relative magnitudes and distances in this system of satellites. The periods of revolution and mean distances, the latter expressed in parts of the equatorial semi-diameter of Saturn, according to the observations of Sir John Herschel at the Cape of Good Hope (630) between 1835 and 1837, are as follows:—

| Satellites according to the time of their discovery. | Satellites according to their distances from the planet. | Period of revolution. | | | | Mean distance. |
|---|---|---|---|---|---|---|
| | | d. | h. | m. | s. | |
| *f.* | 1. Mimas . . | 0 | 22 | 37 | 22·9 | 3·3607 |
| *g.* | 2. Enceladus. | 1 | 8 | 53 | 6·7 | 4·3125 |
| *e.* | 3. Tethys . . | 1 | 21 | 18 | 25·7 | 5·3396 |
| *d.* | 4. Dione . . | 2 | 17 | 41 | 8·9 | 6·8398 |
| *c.* | 5. Rhea . . | 4 | 12 | 25 | 10·8 | 9·5528 |
| *a.* | 6. Titan . . | 15 | 22 | 41 | 25·2 | 22·1450 |
| *h.* | 7. Hyperion . | 22 | 12 | | ? | 28·0000 ? |
| *b.* | 8. Japetus . | 79 | 7 | 53 | 40·4 | 64·3590 |

Between the four first or nearest satellites, we find a remarkable relation in the commensurability of their periods of revolution. The period of the 3d satellite (Tethys), is double that of the 1st (Mimas); and that of the 4th satellite (Dione), is double that of the 2d (Enceladus). The exactness of these proportions amounts to $\frac{1}{800}$ of the longer periods. This result, which has not been much attended to, was communicated to me as early as November 1845, in letters from Sir John Herschel. The four satellites of Jupiter shew also a certain degree of regularity in their distances, the intervals between them presenting with tolerable approximation the series 3, 6, 12. The 2d satellite is dis-

tant from the 1st 3·6; the 3d from the 2d 5·7; and the 4th from the 3d 11·6 semi-diameters of Jupiter. Fries and Challis have attempted to shew that the so-called law of Titius prevails in all the systems of satellites, even in that of Uranus ([631]).

## *Uranus.*

The recognition of the existence of this planet, the great discovery of William Herschel, not only augmented for the first time the number of those six planets which had for thousands of years been known to man, and more than doubled the diameter of the solar domain; it also led, at the end of 65 years, by means of the perturbations sustained by Uranus proceeding from still more distant regions, to the discovery of Neptune. Uranus was discovered accidentally (March 13, 1781) during the examination of a small group of stars in Gemini, and was recognised by means of its minute disk, which, under the successive employment of magnifying powers of 460 and 932, increased much more than did other stars in its vicinity. The keen-sighted and sagacious discoverer, so familiar with all optical phænomena, also remarked, that with increased magnifying powers the intensity of light in the new body decreased considerably; whilst in fixed stars of equal magnitude (between the 6th and 7th) it remained the same.

Herschel termed Uranus, when he first announced its existence ([632]), a comet; and the united labours of Saxon, Lexell, Laplace, and Méchain, which were greatly facilitated by the discovery made by the meritorious Bode, in 1784, of older observations of that body by Tobias Mayer, in 1756,

and by Flamstead, in 1690, established with admirable promptitude the elliptical orbit and all the planetary elements of Uranus. Its mean distance from the Sun is, according to Hansen, 19·18239 distances of the Earth from the Sun, or $396\frac{1}{2}$ millions of geographical miles (1586 millions English geographical miles); its sidereal period of revolution is 84 years, 5 days, 19 hours, 41 minutes, and 36 seconds; its inclination to the ecliptic $0°46'28''$; and its apparent diameter at its mean distance from the Earth $9''·9$. Its mass, which the first observations of its satellites had given at $\frac{1}{17918}$, is derived, by Lamont's observations, as only $\frac{1}{24605}$: according to this, its density would be intermediate between those of Jupiter and Saturn (633). Ellipticity of figure, or compression at the poles, of Uranus, was suspected by William Herschel from observations in which he employed magnifying powers from 800 to 2400: according to Mädler's measurements, in the years 1842 and 1843, its amount would seem to fall between $\frac{1}{10·7}$ and $\frac{1}{9·9}$ (634). That the at first supposed two rings of Uranus were merely the effect of an optical illusion was acknowledged by the discoverer himself, ever so ready to apply due caution, and to continue perseveringly to test the reality of all newly acquired data.

## *Satellites of Uranus.*

"Uranus," says the younger Herschel, "is surrounded by four, or probably by five or six, satellites." They present a remarkable peculiarity, in a feature to which nothing similar has yet been found in any part of the solar system: viz. that whereas all other satellites (those of the Earth, Jupiter, and Saturn), as well as all the primary planets,

move from west to east, and all, excepting some of the asteroids, have orbits but little inclined to the ecliptic, the almost perfectly circular path of the satellites of Uranus is inclined to the ecliptic at an angle of 78° 58′, being therefore nearly perpendicular to it; and the satellites themselves move from east to west. In the satellites of Uranus, as well as in those of Saturn, the sequence or arrangement of the nomenclature, 1st, 2d, 3d, &c., taken from their respective distances from the primary planet, is altogether distinct from the sequence of the epochs of their discovery. Of the satellites of Uranus, those first discovered were the 2d and the 4th, by William Herschel, in 1787; then, in 1790, the 1st and the 5th; and lastly, in 1794, the 6th and the 3d,—all by the same astronomer. In the course of the fifty-six years which have elapsed since the latest discovery (that of the 3d satellite), the existence of so many as six satellites has been often, but unduly doubted; the observations of the last twenty years have gradually shewn how much confidence may be placed in the great discoverer of Slough in this department of planetary astronomy also. Hitherto the satellites of Uranus which have been seen again are the 1st, 2d, 4th, and 6th; to which may perhaps be added the 3d, according to Lassell's observation of the 6th of November, 1848. On account of the large aperture of his reflector, and the abundance of light obtained thereby, the elder Herschel, with his acute vision, considered a magnifying power of 157 sufficient under favourable atmospheric circumstances; his son prescribes generally for these exceedingly small luminous disks a magnifying power of 300. The 2d and 4th satellites are those which have been seen again earliest, most certainly, and most frequently;—in Europe

and the Cape of Good Hope by Sir John Herschel, and subsequently by Lamont at Munich, and Lassell at Liverpool. The 1st satellite of Uranus was rediscovered and observed by Lassell from the 14th of September to the 9th of November, 1847, and by Otto Struve from the 8th of October to the 10th of December, of the same year; and the outermost, or 6th satellite, by Lamont, on the 1st of October, 1837. The 5th satellite does not appear to have been seen again at all; and the 3d not with sufficient certainty (635). These details are not without importance, as suggesting fresh motives for not giving too much weight to so-called negative evidence.*

*Neptune.*

The merit of the successful working out and earliest publication of an inverse problem of perturbation, (viz. the problem of deducing from given perturbations of a known planet the elements of the unknown perturbing one), and even of having occasioned, by a bold prediction, the great discovery of Neptune by Galle, on the 23d of September, 1846, belongs to the acute powers of combination, and to the persevering labours, of Le Verrier (636). It is, as Encke has expressed it, the most brilliant of all planetary discoveries, because purely theoretical investigations caused the antecedent prediction of the existence and the place of the new and yet unknown planet. The promptitude of the

* [See at the close of the present volume a note containing an account of the discovery, by Mr. Lassell, of two more satellites of Uranus, communicated to M. de Humboldt whilst the volume in the original was passing through the press, but after this section had been printed.—EDITOR.]

actual discovery was favoured by the excellent star-maps of the Berlin Academy, by Bremiker [637]. If, among the distances of the outer planets from the Sun, the distance of Saturn (9·53) is approximately twice as great as that of Jupiter (5·20), and the distance of Uranus (19·18) approximately twice as great as that of Saturn,—the distance of Neptune (30·04) would require, in order to complete a similar proportion, to have a third part more, or fully ten Earth-distances, added to it. Our planetary boundary is at the present time 621 millions of German, or 2484 millions of English, geographical miles from the central body; by the discovery of Neptune, the terminal or border-stone, marking the limit of our planetary knowledge, has been made to recede more than 223 millions (892 English) such miles, or upwards of 10·8 distances of the Earth from the Sun. Step by step as the perturbations suffered by each last-known planet are recognised, fresh and fresh planets are discovered, until, by reason of their remoteness, they cease to be visible through our telescopes [638].

According to the latest determinations the period of revolution of Neptune is 60126·7 days, or 164 years and 226 days; and its semi-major axis 30·03628. The excentricity of its orbit is 0·00871946, the least next to that of Venus; its mass is $\frac{1}{14446}$: its apparent diameter is, according to Encke and Galle, 2″·70, and according to Challis even 3″·07; which would give its density as compared to that of the Earth 0·230, greater therefore than that of Uranus 0·178 [639].

Soon after the discovery of Neptune a ring was ascribed to it by Galle, Lassell, and Challis. The first-named of these astronomers had employed a magnifying power of 567,

and tried to determine the great inclination of the supposed ring to the ecliptic; but in the case of Neptune, as long before in that of Uranus, subsequent examination has dispelled the belief in the existence of a ring.

I think it right to forbear, in this work, from more than an allusion to the certainly earlier but unpublished labours,— not therefore crowned by recognised success,—of the highly distinguished and acute English geometrician, John Couch Adams, of St. John's College, Cambridge. The historical facts relating to these labours, and to Le Verrier's and Galle's happy discovery of the new planet, are related circumstantially, impartially, and from well-assured sources of authority, in two memoirs, by the Astronomer-Royal Airy, and by Bernhard von Lindenau ([640]). Intellectual labours directed almost at the same time to the same great object, offer, besides the spectacle of a competition honourable to both competitors, an interest the more vivid, because the selection of the processes employed testifies the brilliant state of the higher mathematical knowledge at the present epoch.

*Satellites of Neptune.*

If, in the outer planets, the existence of a ring has as yet presented itself to our view in one instance only, and if the rarity of this phænomenon causes us therefore to conjecture that the formation of a detached belt of matter is dependent on the concurrence of peculiar conditions difficult of fulfilment; on the other hand, the existence of satellites,— accompanying the outer planets, Jupiter, Saturn, and Uranus,—appears to be a far more general phænomenon. So early as the beginning of August, 1847, Lassell recog-

nised with certainty (641) the first of Neptune's satellites, in his great 20-foot reflector, with an aperture of 24 inches. Otto Struve (642), at Pulkowa (11th Sept. to 20th Dec. 1847), and Bond (643), the Director of the Astronomical Observatory of Cambridge, U.S. (16th Sept. 1847), confirmed Lassell's discovery. The Pulkowa observations gave—the satellite's period of revolution, 5 days, 21 hours, 7 min.; the inclination of its orbit to the ecliptic, 34° 7′; its distance from the centre of the primary planet, 54000 German (216000 English) geographical miles; and its mass, $\frac{1}{14506}$. Three years later (14th August, 1850) Lassell discovered a second satellite of Neptune, to which he applied magnifying powers of 628 (644). This last discovery has not yet, I believe, been confirmed by any other observer.

# III.

## Comets.

In the solar domain, the comets—which Xenocrates and Theon of Alexandria termed "Clouds of Light," and which, according to an ancient belief, handed down from the Chaldeans, were said by Apollonius the Myndian to "ascend periodically from remote distance on long (regulated) paths"—although subject to the attracting force of the central body of our system, form, nevertheless, a peculiar and distinct group. They are distinguished from planetary bodies properly so called, and meaning thereby both primary planets and satellites, not merely by the great excentricity of their orbits, but also by what is still more material—their cutting through or intersecting the orbits of the planets; and they present, moreover, a variability of form—a mutability of outline—which, in some individuals, (for example, in Klinkenberg's comet of 1744 so accurately described by Hensius, and in Halley's comet on its last appearance in 1835), becomes sensible even in the course of a few hours. Before Encke had enriched our knowledge of the solar system with comets of short period,—called interior comets because their orbits are included within some of the planetary orbits,—dogmatic

fancies, based on mistaken analogies respecting a supposed law of increasing excentricity, magnitude, and rarity of matter in planetary bodies with increasing solar distances, led to the view, that beyond Saturn there would be discovered excentric planetary cosmical forms of enormous volume, "constituting intermediate links or gradations between planets and comets; and that the last or outermost planet might even deserve to be called a comet, because it might perhaps be found to intersect the orbit of the preceding planet nearest to itself, *i. e.* Saturn" ([645]). Such a view of the graduated succession of forms in the structure of the Universe, analogous to the often misused doctrine of gradation or transition of form in organic existence, was shared by Kant, one of the greatest intellects of the eighteeenth century. Respectively twenty-six and ninety-one years after the dedication to Frederick the Great of the Naturgeschichte des Himmels by the Königsberg philosopher, Uranus and Neptune were discovered by William Herschel and Galle; but both these planets have a less excentricity than Saturn; indeed, while the excentricity of Saturn is 0·056, that of the outermost of all the planets now known to us, Neptune, is 0·008, nearly the same as that of Venus, so near to the Sun (0·006). In other respects, also, neither Uranus nor Neptune show anything of the anticipated cometary qualities.

As within a recent period, (since 1819), the discovery of five interior comets have followed that of Encke's,—the whole six forming apparently a distinct group, whose semi-major axis does not differ much from that of the majority of the small planets,—the question has been suggested, whether the group of the interior comets may not have originally constituted a single cosmical body,—as in the case of the small

planets according to the hypothesis of Olbers; and whether this original large comet may not have been separated into several parts by the influence of Mars; such a separation, or bi-partition, having actually taken place almost before the eyes of observers, in the year 1846, on the last return of the interior comet of Biela. Certain resemblances between the elements have led Professor Stephen Alexander, of the College of New Jersey, to undertake investigations respecting the possibility of a common origin of the asteroids, (or small planets between Mars and Jupiter,) and some, or even all, of the comets (646). On grounds of analogy founded on the supposed nebulous envelopes of the small planets, all recent and more accurate observations show that the hypothesis is quite unsupported. Other circumstances are also unfavourable to it. Although it is true that the orbits of the small planets are not parallel to each other, and present, indeed, in the case of Pallas, the phænomenon of an excessive inclination, yet with all this want of parallelism in their own paths, they do not, like comets, intersect the orbits of the great, old, or longer known planets. This circumstance, which, in any hypothesis of a primitive impulse in direction and velocity is exceedingly material, taken in conjunction with the diversity in physical constitution between the interior comets and the small planets,—the planets appearing to be entirely without any nebulous or vaporous matter,—seems to render a similarity of origin between these two classes of cosmical bodies very improbable. Laplace, also, in his theory of "planetary genesis" from zones of vapour revolving around the sun and condensing round nuclei, thought that comets must be separated entirely from planets. "Dans l'hypothèse des zones de

vapeurs et d'un noyau s'accroissant par la condensation de l'atmosphère qui l'environne, les comètes sont étrangères au système planétaire" (647).

I have already called attention, in the first volume of my work (648), to the fact that comets combine the smallest mass with the occupation of the largest space within the solar domain; they also exceed all other planetary cosmical bodies in number of individuals; the calculus of probabilities, based on the assumption of an equable distribution of orbits, limits, nearness to the Sun, and possible continued invisibility, leads to our inferring the existence of many thousands. I purposely exclude from such comparative considerations "aerolites," or "meteoric asteroids," because much obscurity still prevails respecting their nature. We must distinguish among comets those whose orbits have been computed by astronomers from those of which we possess, in some cases, only incomplete observations, and in others, mere notices in chronicles. As, according to Galle's latest exact enumeration to the year 1847 inclusive, 178 comets had been calculated, we may very well continue to take as the number of comets which have been seen, including those of which we merely possess notices, a rough total of from six to seven hundred. When the comet of 1682, announced by Halley, reappeared in 1759, it was regarded as something very remarkable that three comets should be visible in the same year. Now, so animated is the examination of the celestial vault, and from so many points of the earth's surface at the same time, that in each of the years 1819, 1825, and 1840, four comets were seen and computed; in 1826, five; and in 1846, even as many as eight.

In comets seen with the unassisted eye, recent times have been more rich than was the latter part of the last century; but still the appearance of a comet brilliant in both head and tail continues to be a rare and remarkable natural phænomenon. It may not be without interest to reckon up the number of comets which have been seen in Europe with the naked eye during the last few centuries ([649]). The richest period was the 16th century, when 23 such comets were seen. The 17th had 12, of which only 2 were in the first half. In the 18th century only 8 such comets appeared, whereas we have had 9 in the first fifty years of the 19th. Of these, the finest were those of 1807, 1811, 1819, 1835, and 1843. In earlier times it has happened more than once that from thirty to forty years have passed without the record of such a spectacle having been once enjoyed. The years which appear poor in comets may, however, for aught we know, have been actually rich in large comets having their perihelions situated beyond the orbits of Jupiter and Saturn. Of telescopic comets, there are now discovered, on an average, at least two or three a year. In three successive months, in 1840, Galle found 3 new comets; from 1764 to 1798 Messier found 12; and Pons, from 1801 to 1827, found 27. Thus Kepler's expression respecting the multitude of comets in space ("ut pisces in oceano") almost appears to be justified.

The careful register of the comets seen in China, made known to us by Edouard Biot from the collection of Ma-tuan-lin, is of no small importance. It extends back beyond the foundation of the Ionic school of Thales and the Lydian Alyattes, and comprises in two sections the places of comets from 613 years before, to 1222 after our era; and from

1222 to 1644 during the period of the dynasty of Ming. I repeat here (Kosmos, Bd. i. S. 389, Anm. 12; Engl. ed. p. xvii. Note 42), that whilst from the middle of the 3d to the end of the 14th century, comets have to be computed exclusively from Chinese observations, the calculation of Halley's comet at its appearance in 1456 is the first which has been made exclusively from European observations: those of Regiomontanus were, however, followed, on the return of Halley's comet, by the very exact ones of Apianus, at Ingolstadt, in August of the year 1531. The appearance of a superb comet which acquired celebrity by means of African and Brazilian voyages of discovery, and which was called by Italians "Signor Astone," the great "Asta," belongs to the intermediate date of May 1500 ([650]). By the similarity of the elements, Laugier ([651]) recognised in the Chinese observations a seventh appearance of Halley's comet (that of 1378): the third comet of 1840, discovered by Galle ([652]) on the 6th of March, appears in the same way to be identical with that of 1097. The Mexicans in their Year-books connected events with comets and other celestial observations. It is a curious fact that it is only in the Chinese Comet-Register that I have been able to recognise, (as having been observed in December of the same year), the comet of 1490, which I discovered in Le Tellier's Mexican Manuscript, and figured in my "Monumens des Peuples indigènes de l'Amérique" ([653]). This comet had been entered by the Mexicans in their register twenty-eight years before Cortes appeared for the first time on the coast of Vera Cruz (Chalchiuheuecan).

I have spoken in detail in the first volume of my work (S. 106—112; English edit. p. 92—98), of the shape and appearance of comets, of their variations of form, brightness

and colour, and of the emanations from the head, which, bending back, form the tail (654), following in my description the observations of Heinsius (1744), Bessel, Struve, and Sir John Herschel. In recent times, besides the magnificent comet of 1843 (655), which was seen by Bowring at Chihuahua (N.W. America) as a small white cloud, from nine in the morning to sunset, and by Amici at Parma, in full noonday, at 1° 23′ east of the Sun (656), the 1st comet of 1847, discovered by Hind in the neighbourhood of Capella, was visible in London on the day of its perihelion, when very near the Sun.

For the further elucidation of what has been said above, respecting the remarks of the Chinese astronomers on the occasion of their observation of the comet of March 837, during the dynasty of Thang, I will here introduce a translation from the Ma-tuan-lin, of the statement of the law followed in the direction of the tails of comets:—"In general, in a comet east of the Sun, the tail, reckoning from the nucleus, is directed to the east; but if the comet appears to the west of the Sun, the tail is turned towards the west." (657). Fracastoro and Apianus say more definitely, and still more correctly, that "a line in the direction of the axis of the tail, prolonged through the head of the comet, strikes the centre of the Sun." The words used by Seneca (Nat. Quæst. vii. 20),—"the tails of comets flee from the Sun's rays,"—are also descriptive of their character in this respect. Among the planets and comets yet known to us, while the proportion of the shortest to the longest period of revolution, dependent on the length of the semi-major axis, is in planets as 1 : 683, in comets it is as 1 : 2670. These ratios are derived from comparing Mercury, having a period of revo-

lution of 87·97 days, with Neptune, whose period is 60126·7 days; and Encke's comet, having 3·3 years, with the comet of 1680, observed by Gottfried Kirch at Coburg, by Newton and by Halley, whose computed period is 8814 years. I have already noticed (Kosmos, Bd. i. S. 116—118, and Bd. iii. S. 371—373; Engl. edit. Vol. i. p. 102—103, and Vol. iii. p. 260—261), the distance of the fixed star nearest to our solar system ($\alpha$ Centauri), from the aphelion (or greatest distance from the Sun) of the last-named comet, as determined by Encke in an excellent memoir on the subject,—the very small velocity, 10 feet in a second, of the same comet at the remotest part of its path,—and the greatest proximity attained by Lexell's and Burckhardt's comet of 1770 to the Earth, (being 6 distances of the Moon from the Earth),—and by the comet of 1680, and still more the comet of 1843, to the Sun. The 2d comet of 1819, which, as seen in Europe, emerged suddenly in considerable magnitude from the Sun's rays, must, according to its elements, have passed on the 26th of June (but, unfortunately, without being seen!) in front of the Sun's disk (658). This must also have been the case with the comet of 1823, which, besides the ordinary tail turned from the Sun, had another turned directly towards the Sun. If the tails of these two comets had a considerable length, vaporous particles belonging to them must have become mingled with our atmosphere, as doubtless has often happened. The question has been propounded, whether the extraordinary mists which, in 1783 and 1831, covered a large part of our continent, may have been the result of such an admixture (659).

While the quantity of radiant heat received by the comets of 1680 and 1843, when in such near proximity to the Sun,

has been compared to the temperature of the focus of a burning-glass of more than 32 inches diameter (660), another highly meritorious astronomer (661) considers that "all comets without a solid nucleus, cannot, from their exceeding tenuity, receive or appropriate any solar heat whatsoever; and have therefore only the temperature of space" (662). If we consider attentively the many and striking analogies in the phænomena presented, according to Melloni and Forbes, by bright and by dark sources of heat, it seems, in the present state and connection of our physical ideas, difficult not to assume processes in the Sun itself which produce, by the vibrations of an ether (by waves of different length), at once radiant light and radiant heat. Mention was long made in many astronomical works of a supposed occultation of the Moon by a comet, in 1454, the statement of which the Jesuit Pontanus, the first translator of the Byzantine writer George Phranza, thought he had discovered in a Munich manuscript. This supposition of the passage of a comet between the Earth and the Moon, in 1454, is as erroneous as is a similar assertion by Lichtenberg in respect to the comet of 1770. Phranza's Chronicles were published in full for the first time, in Vienna, in 1796; and it is said in them expressly, that in the year of the world 6962, during the time that an eclipse of the Moon was taking place, quite in the ordinary manner, according to the order and circular path of the heavenly luminaries, a comet, similar to a mist, appeared, and came near to the Moon. The date, corresponding to 1450, is given incorrectly; for Phranza says positively that the lunar eclipse and the comet were seen *after* the taking of Constantinople (19th of May, 1453); and an eclipse of the Moon did really take place on the 12th

of May, 1454. (See Jacobs in Zach's Monatl. Corresp. Bd. xxiii. 1811, S. 196—202).

The facts relative to Lexell's comet and Jupiter's satellites, *i. e.* the disturbances which it sustained from them without sensibly influencing their periods of revolution (Kosmos, Bd. i. S. 117; English edit. Vol. i. p. 103), have undergone more accurate investigation by Le Verrier. Messier discovered this remarkable comet on the 14th of June, 1770, as a faint nebula in Sagittarius; but eight days later its nucleus shone already like a s tar of th 2d magnitude. Previous to the perihelion no tail was visible; but afterwards one developed itself, by slight emanations, to a length of barely 1°. Lexell found for his comet an elliptic path, and a period of revolution of 5·585 years, a result which was confirmed by Burckhardt in his excellent prize memoir of 1806. According to Clausen it approached the Earth, on the 1st of July, 1770, within 363 semi-diameters of the Earth (311000 German, or 1244000 English geographical miles, or six distances of the Moon from the Earth). That the comet should not have been seen earlier (March 1776), and later (October 1781), has, in accordance with Lexell's previous conjecture, been made out analytically by Laplace, in the 4th volume of the Mécanique celeste, as the effect of perturbations proceeding from the direction occupied by Jupiter's system at the time of the approximations, in the two years 1767 and 1779. Le Verrier finds that, according to one hypothesis respecting the comet's path, it should have passed, in 1779, through the orbits of the satellites of Jupiter; and that, according to another hypothesis, it should have passed far outside the 4th or outermost satellite [663].

The molecular state of the head or nucleus, which presents so singular an outline, as well as of the tail of comets, is the more difficult to comprehend, since it does not cause any refraction of rays, and since, by Arago's important discovery (Kosmos, Bd. i. S. 111, 391 and 392, Anm. 19—21; English edit. p. 97, xviii. and xix., Notes, 49—51), the light of comets has been shewn to consist partly of polarised, and therefore of reflected solar light. While the smallest stars are seen to shine with undiminished brightness through the vaporous emanations which form the tail, and even through almost the centre of the nucleus itself, or at least exceedingly near to the centre (per cometem non aliter quam per nubem ulteriora cernuntur; Seneca, Nat. Quæst. vii. 18), the analysis of the light of comets in Arago's experiments which I witnessed shows, on the other hand, that the vaporous envelopes are capable, notwithstanding their tenuity, of reflecting or giving back light received from a foreign source (664); that these cosmical bodies have "an imperfect transparency (665); and that light does not pass through them unimpeded." In a group of nebulous bodies of such extreme tenuity, the particular instances of great luminous intensity, as in the comet of 1843, or the star-like brightness of a nucleus, excite the more astonishment, because the reflection of the Sun's light is assumed to be the exclusive cause. But may we not suppose in comets, in addition to this, a light-evolving process of their own?

The particles emanating or evaporating from brush-like or fan-shaped comets' tails of many millions of miles in length, disperse themselves in space, and may perhaps either form of themselves the resisting or impeding fluid or medium (666) which gradually contracts the path of Encke's

comet, or may mingle with the ancient cosmical matter which has not been condensed either into celestial bodies or into the ring which forms our Zodiacal Light. We see material particles disappear, as it were, before our eyes, and can hardly conjecture where they reassemble. Now, however probable may be the condensation in the neighbourhood of the central body of our system of a gaseous fluid filling space, yet in comets, whose nucleus, according to Valz, becomes small in the vicinity of the Sun, we cannot well imagine to ourselves that this effect is caused by the surrounding fluid being there more dense, and thus pressing upon and contracting a vesicular nebulous envelope (667). If, in the emanations of comets, the outlines of the light-reflecting nebulosity are usually very little defined, it is the more striking, and the more instructive in respect to the molecular state of the body, to remark that, in particular cases and individuals (for example, in Halley's comet, seen at the end of January 1836 at the Cape of Good Hope), there has been observed in the parabolic front part of the comet such a well-marked and definite outline, as we hardly ever see in the piled up clouds or cumuli of our atmosphere. The illustrious observer at the Cape compared the unusual appearance, indicative of the strength of the mutual attraction of the particles, to an alabaster vessel strongly illuminated from within (668).

Since the appearance of the first volume of my work, an occurrence has presented itself among the bodies of which we are treating, the mere possibility of which could scarcely have been anticipated. Biela's comet, (an interior comet of short period of revolution, $6\frac{3}{5}$ years), parted asunder and formed two comets, similar in form though unequal in

size, each exhibiting both a head or nucleus, and a tail. So long as they could be observed they did not reunite, but were moving onward separately and almost parallel to each other. As early as the 19th of December, 1845, Hind had remarked in the still undivided comet a kind of protuberance towards the north: on the 21st, when observed by Encke at Berlin, nothing resembling a division could yet be seen. On the 29th, the division which had then taken place, was first seen and recognised in North America; in Europe it was not perceived until the middle and end of January, 1846. The new smaller comet moved foremost towards the north. The distance between the two was at first 3, and afterwards (20th of February), according to Otto Struve's interesting drawing, 6 minutes (669). The strength of the light varied, so that the light of the gradually increasing second comet was for a time greater than that of the first or original comet. The nebulous envelopes surrounding each of the two nuclei had no definitely marked outlines: in the larger comet there was even, towards the S.S.W., a swelling of very faint light; but the space between the two comets was seen at Pulkowa to be entirely free from nebulosity (670). Some days later, Lieutenant Maury, at Washington, noticed with a 9-inch Munich refractor rays sent by the larger older comet to the smaller new one, so that there was for a time a sort of bridge-like connection between them. On the 24th of March, the smaller comet, from the increasing faintness of its light, could but just be recognised. Afterwards the larger comet was alone seen up to the 16th or 20th of April, when it also vanished. I have described the particulars of this wonderful phænomenon (671) so far as it was possible to observe them: unhappily the act of separa-

tion, and the state of the older comet a short time previously, escaped observation. Did the separated comet become invisible solely from increasing distance and great faintness of light, or did it dissolve? Will it again appear and be recognised as a companion? and will Biela's comet on future reappearances present to us similar anomalous phænomena?

The production of a new planetary cosmical body by division, naturally suggests the question, whether, in the multitude of comets revolving round the Sun, several may not have originated, or may originate from time to time, by a similar process? and whether, by retardation, *i. e.* unequal velocity of revolution, and by unequal influence of perturbations, different orbits may not be produced? In a memoir by Stephen Alexander, to which I have already alluded, it is attempted to explain the origin of all the interior comets by the adoption of such an hypothesis, which cannot, indeed, be said to rest on any adequate foundation. It would seem as if similar cosmical events had been observed, but not sufficiently well described, by the ancients. Seneca relates,—but, indeed, as he himself states, not on trustworthy testimony,—that the comet, to which the downfall of the cities of Helice and Bura was attributed, divided asunder into two parts. He adds, mockingly—"Why is it that no one has yet seen two comets unite into one?" (672) The Chinese astronomers speak of three "double," or "couples of," comets, which appeared in 896, and went through their course together (673).

Among the great number of comets whose course has been computed, there are eight whose periods of revolution are of shorter duration than the period of revolution of Neptune. Of these eight, six are interior comets, *i. e.* comets

whose aphelia are less distant from the Sun than is a point in the orbit of Neptune: they are—Encke's comet (aphelion 4·09); de Vico's (5·02); Brorsen's (5·64); Faye's (5·93); Biela's (6·19); and d'Arrest's (6·44). The Earth's mean distance from the Sun being unity, the paths of all these six interior comets have aphelia situated between Hygeia (3·15) and a limit which is placed almost $1\frac{1}{4}$ distances of the Earth beyond Jupiter (5·20). The two other comets which have also shorter periods of revolution than Neptune, are Olbers's comet, having a period of 74, and Halley's, having a period of 76 years. Up to the year 1819, when the existence of an interior comet was first recognised by Encke, the above-named two comets were those which had the shortest known periods of revolution. The aphelia of Olbers's comet of 1815, and of Halley's comet, are situated only 4 and $5\frac{2}{5}$ distances of the Earth from the Sun beyond the limit at or within which, according to the discovery of Neptune, they would be considered interior comets. Although the application of the term "interior comet" may undergo alteration by the future discovery of trans-Neptunian planets, since the limit which renders comets "interior" is a variable one, yet the term is preferable to that of "comets of short period," inasmuch as it depends at every epoch of our knowledge on something definite at that epoch. The six interior comets which have now been securely computed, only vary indeed in their periods of revolution from 3·3 to 7·4 years; but if the expectation of the return at the end of 16 years of the comet discovered by Peters at Naples, on the 26th of June, 1846 (the 6th comet of the year 1846, with a semi-major axis of 6·32), should be confirmed (674), it may be anticipated that, as respects the

duration of the period of revolution, intermediate links will gradually be discovered between the comets of Olbers and of Faye, and that it will in future be difficult to determine any fixed limit defining "shortness of period." I subjoin the table in which Dr. Galle has collected the elements of the six interior comets (see p. 410).

It follows from this review, that from the recognition of Encke's [675] as an interior comet, in 1819, to the discovery of the last interior comet of d'Arrest, 32 years only have elapsed. Elliptic elements for the last-named comet have also been computed by Yvon Villarceau, in Schumacher's Astr. Nachr. No. 773, who, as well as Valz, has expressed some conjectures respecting its possible identity with the comet of 1678, observed by La Hire, and calculated by Douwes. Two other comets, apparently also having periods of revolution of five or six years, are—the 3d of 1819, discovered by Pons, and calculated by Encke; and the 4th of 1819, found by Blanpain, and considered by Clausen to be identical with the 1st of 1743. Neither of these comets, however, can yet be classed with those in regard to which long-continued and exact observations permit greater certainty and completeness in the assigned elements.

The inclination of the paths of the interior comets to the ecliptic is, generally speaking, small, *i. e.* between 3° and 13°: in Brorsen's comet only it is considerable, attaining 31°. All the interior comets which have yet been discovered, have, like all the planets and satellites of the solar system, a direct motion (advancing in their orbits from west to east). Sir John Herschel has called attention to the greater rarity of retrograde motion in those comets whose degree of inclination to the ecliptic is small [676]. This opposite direction

## More exactly calculated Elements of the 6 Inner Comets.

| | Encke. | de Vico. | Brorsen. | d'Arrest. | Biela. | Faye. |
|---|---|---|---|---|---|---|
| Epoch of the passage through the perihelion in mean Paris time ...... | 1848, Nov. 26 $2^h\ 55^m\ 56^s$ | 1844, Sept. 2 $11^h\ 33^m\ 57^s$ | 1846, Feb. 25 $9^h\ 8^m\ 1^s$ | 1851, July 8 $16^h\ 57^m\ 23^s$ | 1846, Feb. 10 $23^h\ 51^m\ 36^s$ | 1843, Oct. 17 $3^h\ 42^m\ 16^s$ |
| Longitude of the Perihelion ...... | 157° 47′ 8″ | 342° 30′ 55″ | 116° 28′ 15″ | 322° 59′ 46″ | 109° 2′ 20″ | 49° 34′ 19′ |
| Longitude of the Ascending Node | 334 22 12 | 63 49 17 | 102 40 58 | 148 27 20 | 245 54 39 | 209 29 19 |
| Inclination to the Ecliptic ...... | 13 8 36 | 2 54 50 | 30 55 53 | 13 56 12 | 12 34 53 | 11 22 31 |
| Semimajor axis ...... | 2·214814 | 3·102800 | 3·146494 | 3·461846 | 3·524522 | 3·811790 |
| Perihelion distance ...... | 0·337032 | 1·186401 | 0·650103 | 1·173976 | 0·856448 | 1·692579 |
| Aphelion distance ...... | 4·092595 | 5·019198 | 5·642884 | 5·749717 | 6·192596 | 5·931001 |
| Excentricity ...... | 0·847828 | 0·617635 | 0·793388 | 0·660881 | 0·757003 | 0·555962 |
| Period of revolution in days ...... | 1204 | 1996 | 2039 | 2353 | 2417 | 2718 |
| Period of revolution in years ... | 3·30 | 5·47 | 5·58 | 6·44 | 6·62 | 7·44 |
| Calculated by ...... | Encke, Astr. Nachr. xxvii. p. 113. | Brünnow, Prize Memoir, Amst. 1849. | Brünnow, Astr. Nachr. xxix. p. 377. | d'Arrest, Astr. Nachr. xxxiii. p. 125. | Plantamour, Astr. Nachr. xxv. p. 117. | Le Verrier, Astr. Nachr xxiii. p. 196. |

of motion, which exists only in a certain class of bodies belonging to the solar system, is of great importance in reference to a very generally prevailing opinion respecting the origin of celestial bodies belonging to one system, and respecting primitive impulse. It appears to shew us the comet-world, though placed in the remotest distance, subjected to the attraction of the central body, yet possessing greater individuality than the planets. Such a consideration has led, unduly, to the idea of comets being older than planets (677),—of their being, as it were, primeval forms of imperfectly condensed cosmical matter in space. Under this supposition it has been asked whether, notwithstanding the enormous distance of the nearest fixed star of which we know the parallax from the aphelion of the comet of 1680, some of the comets which come within our view may not be wanderers passing through our system, from the domain of one sun to that of another?

I propose to place next to the class of comets, as with great probability belonging to the solar domain, the Ring of the Zodiacal Light; and next to that, the multitude of meteoric asteroids which sometimes fall upon our Earth, and respecting the existence of which as bodies in cosmical space unanimity of opinion by no means prevails. As I myself, conformably to the examples of Chladni, Olbers, Laplace, Arago, John Herschel, and Bessel, decidedly regard aerolites as being of extra-terrestrial cosmical origin, I may naturally close the present section on those cometary bodies, which have been sometimes termed "wandering stars," with the expression of a confident expectation, that by increasing care and accuracy in the observation of aerolites, fireballs, and falling stars, the oppo-

site opinion will disappear, as the opinion which generally prevailed up to the 16th century of the meteoric origin of comets has long since done. Although in ancient times the astrological corporation of the "Chaldeans in Babylon," a large part of the Pythagorean school, and Apollonius the Myndian, regarded comets as celestial bodies, returning at determinate periods in long planetary paths,—on the other hand, the powerful anti-Pythagorean school of Aristotle and Epigenes, combated by Seneca, declared them to be products of meteorological processes in our atmosphere ([678]). Analogous fluctuations of opinion between cosmical and telluric hypotheses, between external space and the atmosphere of our own planet, will in the end conduct us, in the case of aerolites also, to the reception of just views.

# IV.

## RING OF ZODIACAL LIGHT.

In our richly varied Solar System, several of the distinct classes of bodies of which it consists have only been recognised by us in their existence, place, and form, at successive intervals of time, in the last two centuries and a half. There have thus been made known to us:—First, subordinate or particular systems, in which, in analogy with the chief or general system of the solar domain, smaller cosmical sphereodised bodies revolve around a larger one;—next, the existence of concentric rings surrounding one of the less dense exterior planets, being also the one amongst them which is most rich in satellites;—next, the existence and the probable material cause of the mild, pyramidally shaped, Zodiacal Light, very visible to the unassisted eye;—next, the mutually intersecting orbits of what are called the small planets or asteroids, situated beyond the zodiacal zone, and included between the domains of two primary planets;—and lastly, the remarkable group of inner comets, whose aphelia are less

remote than the aphelia of Saturn, of Uranus, or of Neptune. In a cosmical presentation or description of the Universe, it is right to recall this variety or diversity between different members of the solar system, which, however, by no means excludes uniformity of origin and permanent dependence on the same motive forces.

Great as is still the obscurity which surrounds the material or physical cause of the Zodiacal Light, yet, considering the mathematical certainty that the limits of the Sun's atmosphere cannot extend beyond $\frac{9}{20}$ of the distance of Mercury, the opinion contended for by Laplace, Schubert, Arago, Poisson, and Biot,—according to which the Zodiacal Light is supposed to proceed from a detached, vaporous, flattened ring, revolving freely in space between the orbits of Venus and Mars,—would seem the most satisfactory hypothesis which presents itself in the present very defective state of our knowledge. In the Sun, as well as in Saturn (a subordinate system), the outermost limit of the atmosphere can only extend to where the attraction of the central body (whether primary or secondary) exactly balances the centrifugal force: the portions of the atmosphere which may have passed beyond this limit become detached, and must pursue their course either condensed into spheroidal planets or satellites, or, if not in the form of spheres, in that of solid or of vaporous rings. According to this view, the "Ring of the Zodiacal Light" would take its place in the category of planetary forms, subject to the general laws of their formation.

From the small progress in respect to observation which has been made in this neglected part of our astronomical

knowledge, I have little to add to what I have already said concerning it, derived from my own experience and from that of others (Kosmos, Bd. i. S. 142—149, and 409—414, Anm. 61—78; Bd. iii. S. 323: English edit. Vol. i. p. 127—133, and xxxiii.—xxxvii. Notes 91—99; Vol. iii. p. 228). Twenty-two years before the Zodiacal Light was seen and noticed by Dominique Cassini, to whom its first observation is commonly ascribed, Childrey (Chaplain to Lord Henry Somerset), in his Britannia Baconica, published in 1661, recommended it to the attention of astronomers as a previously undescribed phænomenon, which he had seen for several years in the month of February and in the beginning of March. I think it also right to remind my readers of a letter from Rothmann to Tycho Brahe (noticed by Olbers), from which it appears that, as early as the end of the 16th century, Tycho had seen and remarked the shining of the Zodiacal Light, and had taken it for an abnormal vernal evening twilight. I was myself first stimulated to make this phænomenon the object of persevering observation, from being struck, as I was quitting Europe, with its increasing brightness in Spain, on the coast of Valencia, and in the plains of New Castille. I found that the strength of the light, I might almost say of the illumination, increased astonishingly as I approached the equator in South America and in the Pacific. In the ever-dry clear air of Cumana, in the grassy steppes (Llanos) of Caracas, on the high table-lands of Quito and the Mexican Lakes, and more particularly at elevations from eight to twelve or thirteen thousand feet, where I was able to remain for a longer time, I found its brightness sometimes surpass that of the finest parts of the Milky Way,

between the front part of the constellation of the Ship and Sagittarius; or, to name portions of the heavens visible in our own hemisphere, between Aquila and Cygnus.

On the whole, however, the brightness of the Zodiacal Light did not appear to me to increase sensibly with the elevation of the observer's station, but rather to depend principally on internal variations, *i. e.* on greater or less degrees of luminous intensity in the phænomenon itself. I even remarked, when in the Pacific, a counter-glow, like that of sunset. I have said, depending "*principally*" on internal variations, because I by no means deny the possibility of a concurrent influence from the greater or less transparency of the upper strata of the atmosphere, while in its lower strata my instruments indicated no hygrometric changes, or sometimes such as would have had an opposite tendency. Advances in our knowledge of the Zodiacal Light may be most hopefully looked for from the tropical regions, where meteorological processes attain the greatest degree either of uniformity or of regularity in their periodical variations. The phænomenon is there perpetual: and a careful comparison of observations at stations of different elevation, and under different local circumstances, would enable us to decide, by the aid of the calculus of probabilities, what we ought to ascribe to cosmical luminous processes, and what to mere meteorological influences.

It has been stated more than once, that for several successive years scarcely any Zodiacal Light, or only a very faint trace of it, has been seen in Europe. Does the light appear proportionally enfeebled in the equatorial zone in years when this is the case? Such an investigation, how-

ever, must not be limited to the configuration of the light, derived either from distances from known stars, or from direct measurements. The intensity of the light, its uniformity, or, on the other hand, its intermittence (quivering and flashing), and its analysis by the polariscope, ought to be the chief objects of examination. Arago (in the Annuaire for 1836, p. 298) has already pointed out that a comparison of the observations of Dominique Cassini is perhaps sufficient to show "que la supposition des intermittences de la diaphanité atmosphérique ne saurait suffire à l'explication des variations signalées par cet astronome."

Immediately after the first Paris observations of this great observer, and of his friend, Fatio de Duillier, the Zodiacal Light attracted the regard of the Indian voyagers, Pater Noel, de Bèze, and Duhalde; but detached notices (for the most part chiefly occupied with describing the gratification afforded by the unwonted spectacle) are not available for a thorough discussion of the causes on which the variability of the light depends. It is not on rapid journeys, or voyages called voyages of circumnavigation, as the endeavours of the active Horner have shewn in more recent times (Zach, Monatl. Corresp. Bd. x. S. 337—340), that the desired object can be attained in a thorough and satisfactory manner. A permanent residence of several years in some of the countries of the tropics is requisite for obtaining the solution of the problems, presented by the variations in form and intensity of the Zodiacal Light. For this object, as well as for meteorology generally, the greatest advantages may be expected, when scientific cultivation shall at length have extended over the equinoctial regions formerly called Spanish America,

where large populous cities—Cuzco, La Paz, and Potosi—are situated at 10700 and 12500 (about 11400 and 13320 English) feet above the level of the sea. The numerical results at which Houzeau has been able to arrive, and which, indeed, could only be based on a small number of accurate observations, render it probable that the major axis of the Ring of the Zodiacal Light does not coincide with the plane of the Sun's equator, and that the vaporous mass of the Ring, whose molecular condition is wholly unknown to us, does not pass beyond the Earth's orbit (Schum. Astr. Nachr. No. 492).

# V.

## FALLING STARS, BALLS OF FIRE, AND METEORIC STONES.

SINCE the spring of 1845, when I published the first volume of Kosmos, containing the Picture of Nature or General View of Cosmical Phænomena, the earlier results of observation of falls of Aerolites, and of periodical streams of falling stars which were then at my disposal, have been largely augmented, thus rendering our knowledge on the subject in many ways more extensive and more correct. Many questions have undergone stricter and more critical examination, more especially the very important one of what has been called "radiation," *i. e.* points of departure from whence the shooting stars appear to proceed, at the recurring epochs or periods at which they are seen to fall in unusual abundance. Recent observations, the results of which present a high degree of probability, have also augmented the number of such epochs, of which the August and November periods were for a long time the only ones which attracted attention. The meritorious exertions, first of Brandes, Benzenberg, Olbers, and Bessel; and subsequently of Erman, Boguslawski, Quetelet, Feldt, Saigey, Eduard Heis, and Julius Schmidt, have led

to the employment of more exact corresponding measurements; while at the same time a more widely prevailing mathematical training has rendered observers less liable to persuade themselves of the accord of uncertain observations with a previously conceived theory.

The progress of our knowledge respecting igneous meteors will be the more rapid the more impartially facts are separated from opinions, so that while carefully sifting or testing all alleged particular facts, on the one hand, we may not, on the other, fall into the error of rejecting as bad or as uncertain observations, whatever results we are not yet able to explain. It appears to me most important to separate physical relations, from those geometrical and numerical relations which admit, generally speaking, of more certain and assured investigation. To this latter class belong—altitude; velocity; unity or multiplicity of points of departure where "radiation" is recognised; mean number of igneous meteors, whether in sporadic or periodic phænomena, reduced, in order to determine their frequency, to the same standard of measure in time, magnitude, and form,—all being considered in connection with the seasons of the year, and with hours, or intervals before and after midnight. The investigation of both classes of circumstances or relations, viz. the physical and the geometrical, will gradually lead to one and the same object, *i. e.* to "genetic" considerations on the true nature and character of these phænomena.

I have before pointed out that, generally speaking, our communication with the regions of cosmical space is solely through light- and heat-exciting undulations, and through the mysterious forces of attraction, exerted by distant masses or celestial bodies according to the quantity of their material

particles, on our globe, its oceans, and its atmosphere. The luminous vibration which proceeds from the smallest telescopic fixed star in a resolvable nebula, to the impression of which our eye is susceptible, brings to us, (as is mathematically shewn by the sure knowledge we possess of the velocity and aberration of light), the evidence of the most ancient existence of matter of which we are cognisant ([679]). By a simple combination of ideas, a luminous impression received from the depths of star-filled space leads us back more than a myriad of ages into the depths of primeval time. The luminous impression given by streams or showers of falling stars, aerolite-discharging fire-balls, or similar igneous meteors, are of a wholly different nature, since they only kindle or become ignited on arriving at or entering the Earth's atmosphere; and, on the other hand, the falling aerolite affords the only instance of actual material contact with something foreign to our globe. "Accustomed to know non-telluric bodies solely by measurement, by calculation, and by the inferences of our reason, it is with a kind of astonishment that we touch, weigh, and submit to chemical analysis, metallic and earthy masses appertaining to the world without,"—to the celestial spaces external to our planet; and that we find in them our native minerals, rendering it probable, as was already conjectured by Newton, that substances belonging to one group of cosmical bodies, or to one planetary system, are for the most part the same ([680]).

We are indebted to the diligence of the Chinese, and to their habit of recording everything in registers, for the oldest chronologically determined falls of aerolites. Accounts of this kind go back to 644 years before our era; therefore to the time of Tyrtæus and of the second Messenian War of the

Spartans, 176 years before the fall of the enormous meteoric mass at Ægos Potamoi. Edouard Biot has discovered in the Ma-tuan-lin, which contains extracts from the astronomical section of the oldest imperial annals, 16 falls of aerolites for the interval between the middle of the 7th century B.C. and the 333d year of our era; whereas Greek and Roman writers mention only 4 such phænomena for the same interval.

It is worthy of remark, that the Ionic school, in early accordance with our present opinions, assumed the cosmical origin of meteoric stones. The impression made on all the Hellenic nations by so grand a phænomenon as that of Ægos Potamoi (at a spot which 62 years later was rendered still more celebrated by the victory of Lysander over the Athenians, which terminated the Peloponnesian War), must have exercised a decided and not sufficiently regarded influence on the direction and development of the Ionic Physical Philosophy ([681]). Anaxagoras of Clazomene was at the ripe age of 32 years when this remarkable event in nature took place. He viewed the heavenly bodies in general as stony masses torn off from the Earth by the violent action of the revolving force (Plut. de plac. Philos. iii. p. 13; and Plato de legib. xii. p. 9667), and deemed that these solid stony bodies were rendered glowing by the fiery æther, so that they radiate back the light imparted to them by the æther. According to Theophrastus (Stob. Eclog. phys. lib. i. p. 560), Anaxagoras said that, lower than the Moon, and between it and the Earth, there move yet other dark bodies, which may occasion eclipses of the Moon (Diog. Laert. ii. 12; Origenes, Philosophum, cap. 8). Diogenes of Apollonia, who, though not a scholar of Anaximenes ([682]), probably belonged to a

period intermediate between Anaxagoras and Democritus, expresses himself still more clearly respecting the structure of the Universe. According to him, as I have already remarked elsewhere, "together with the visible stars there move other invisible ones, which are therefore without names. These sometimes fall upon the Earth and are extinguished, as took place with the star of stone which fell at Ægos Potamoi" (Stob. Eclog. p. 508) ([683]).

The "opinion of some natural philosophers" respecting igneous meteors (falling stars and aerolites), developed in detail by Plutarch in the Life of Lysander (cap. 12), is quite that of the Cretan Diogenes. It is there said, "falling stars are not emanations or rejected portions thrown off from the ethereal fire, which, when they come into our atmosphere, are extinguished after being kindled; they are rather celestial bodies, which, having once had an impetus of revolution, fall, or are cast down, to the Earth by its intermission" ([684]). We find nothing of this view of the structure of the Universe, or of the assumption of dark bodies which fall on our Earth from the celestial regions, in the teaching of the *ancient* Ionic school, from Thales and Hippo to Empedocles ([685]). The impression of the great natural event above alluded to, which took place in the 78th Olympiad, appears to have had a powerful effect in calling forth ideas connected with the fall of dark masses. In the late pseudo-Plutarch writings (Plac. ii. 13), we merely read that the Milesian Thales regarded "all the heavenly bodies as earthy and igneous bodies (γεωδη και εμπυρα)." The efforts and tendencies of the *early* Ionic physiology were directed to seeking out the primeval beginning of things; the origin of substances by mixture, and their gradual alteration and transi-

tion into one another; and to processes of formation by solidification or by rarefaction. The revolution of the celestial sphere, "which keeps the Earth steadfast in the centre," is, indeed, already mentioned by Empedocles as an active moving cosmical force. As in these first remote preludes, as it were, to physical theories of an æther, the fiery air, and even fire itself, represent the expansive force of heat, so there was connected with this upper æthereal region the idea of an impetus of revolution tearing away rocky fragments from the Earth. Hence Aristotle (Meteorol. i. 339, Bekker) terms the æther "the for-ever-moving body"—as it were, the immediate substratum of motion,—and seeks etymological reasons for this assertion (686). Therefore we find in the biography of Lysander, "that the intermission of the rotative force causes the fall of heavenly bodies;" as also in another place, where Plutarch is evidently alluding to the opinions of Anaxagoras, or of Diogenes of Apollonia (de Facie in Orbe Lunæ, p. 923), he puts forward the statement, "that the Moon, if its force of revolution ceased, would fall to the Earth, like the stone in the sling" (687). We see in this comparison of the sling, how the idea of a centrifugal force of rotation or revolution, which Empedocles recognised in the (apparent) revolution of the celestial sphere, gradually came to have associated with it the corresponding, or counterpart, idea of a centripetal force. This force was more clearly and specifically indicated by the most sagacious of all the elucidators of Aristotle, Simplicius (page 491, Bekker). He proposes to explain the "non-falling" of the heavenly bodies by the "force of revolution prevailing over the proper falling force, or downward traction." These are the first presentiments or anticipations respecting

active central forces; and in a similar manner, recognising as it were the inertness or force of inertia in matter, John Philoponus, of Alexandria, a scholar of Ammonius Hermeæ, and probably also of the 6th century, ascribes "the motion of the revolving planets to a primitive impetus," which he combines with the idea of "falling," *i. e.* the idea of "a tendency in all matter, heavy or light, towards the Earth" (de Creatione Mundi, lib. i. cap. 12). We have thus attempted to shew how a grand natural phænomenon, and the earliest purely cosmical explanation of the fall of aerolites, contributed materially to promote, in Grecian antiquity, the gradual development, not indeed by mathematical combination, of the germs of that which, by the mental labour of succeeding centuries, led to the recognition of the laws of circular motion discovered by Huygens.

Commencing with the geometric relations of periodical (not sporadical) falling stars, we direct our attention by preference to that which more recent observations have shewn concerning the "radiation," or "points of departure," of the meteors, and their wholly "planetary velocity." Both these features, of "radiation" and "velocity," characterise them, with a high degree of probability, as luminous bodies independent of the Earth's rotation, arriving in our atmosphere from "without," or from the regions of space. The North American observations of the "November period," on the occasions of the showers of falling stars in that month, in the years 1833, 1834, and 1837, had caused the direction of the star $\gamma$ Leonis to be indicated as the point of departure; and the observations of the "August phænomenon," in 1839, indicated, in the same way, the star Algol in the constellation of Perseus, or a point between

Perseus and Taurus. Approximately, these points or "radiation-centres" were the constellations towards which the Earth was moving at the respective epochs (688). Saigey, who had submitted all the American observations of 1833 to a very exact investigation, remarked that the steady radiation from the constellation of Leo was observed, strictly speaking, only after midnight, in the last three or four hours before day-break; and he further notices, that out of 18 observers between the city of Mexico and Lake Huron, only 10 recognised the same general point of departure of the meteors as did Denison Olmsted, Professor of Mathematics at Newhaven, Massachusetts (689).

The excellent memoir of Eduard Heis, at Aix-la-Chapelle, which presents in a brief and condensed form very exact observations made by himself on periodical returns of falling stars at Aix during ten years, contains results respecting the "centres of radiation," which are the more important because the observer has submitted them to a rigid mathematical discussion. According to him (690), the falling stars of the November period are characterised by their paths being more dispersed than those of the August period. But in each of the two periods there were observed to be, simultaneously, more points of departure than one, these being by no means always situated within the same constellation, as since 1833 had been too hastily assumed. Heis found in the August periods of 1839, 1841, 1842, 1843, 1844, 1847, and 1848, in addition to the principal point of departure in Perseus, two others situated in Draco and in the North Pole (691). "In order to obtain accurate results in respect to the points of departure of the paths of falling stars in the November period, in the years

1839, 1841, 1846, and 1847, the mean paths belonging respectively to each of the 4 points (in Perseus, Leo, Cassiopeia, and the head of Draco), were laid down separately on a 30-inch celestial globe, and the position of the point from which the greatest number of paths took their departure was on every occasion deduced. The result derived from the investigation was, that out of 407 falling stars of which the paths were marked, 171 proceeded from the constellation of Perseus, near the star $\eta$ in the head of Medusa, 83 from Leo, 35 from the part of Cassiopeia near the variable star $\alpha$, 40 from the head of Draco, and fully 78 from undetermined points. Thus the falling stars which radiated from Perseus were almost twice as numerous as those from Leo" ([692]).

The radiation from Perseus would appear a very remarkable fact, as having shewn itself in both periods. An acute observer, who has been occupied for eight or ten years with the phænomena of meteors, Julius Schmidt, Assistant at the Astronomical Observatory at Bonn, expresses himself very distinctly on this subject, in a letter to myself, written in July 1851:—"Abstracting the abundant falls of shooting stars of November 1833 and 1834, as well as some later ones, in which the point in Leo seemed to send forth swarms of meteors, I am at present inclined to regard the point of convergence in Perseus as that which furnishes the greatest number of meteors, not only in August, but throughout the year. Taking as my basis the values derived from 478 observations by Heis, I find that this point is situated in 50° 3′ R.A., and 51° 5′ Decl.: this applies to the years 1844—1846. In November 1849 (7th to 14th), I saw two hundred more falling stars than, since 1841, I had ever observed in the month of November. Of these, generally

speaking, only a few came from the constellation of Leo; by far the greater number from that of Perseus. Hence it appears to me to follow, that the *great* November phænomenon of 1799 and 1833 did not reappear at that time (1841). Olbers also believed the maximum effect in the November phænomenon to have a period of 34 years (Kosmos, Bd. i. S. 132; English edit. p. 117). If we consider the directions of the paths of the meteors in all their complication, and have regard to their periodical return, we find that there are certain points or centres of radiation which always recur, and others which appear only sporadically and in a variable manner."

Whether the different points of departure vary from year to year,—which, if we assume the existence of "closed rings," would indicate an alteration in the situation of the rings in which the meteors move,—cannot as yet be certainly determined from the observations. A fine series of such observations, by Houzeau (in the years 1839—1842), appears to testify against a progressive variation ([693]). Eduard Heis has shewn very justly ([694]) that in Greek and Roman antiquity, attention had already been drawn to a certain temporary uniformity in the direction in which the falling stars shot across the celestial vault: this direction was then regarded as the effect of a wind already beginning to blow in the higher parts of the atmosphere, and was thus believed to announce to navigators an approaching gale from the same quarter, which might be expected to descend from the upper to the lower regions.

If the periodical streams of shooting stars are distinguished from sporadical ones by the general parallelism of the paths, or by their radiating from one or more determinate points of departure, a second criterion is also afforded by the num-

bers in a given interval of time. This brings us to the much contested problem of the distinction between an extraordinary and an ordinary fall of shooting stars. Two excellent observers, Olbers and Quetelet, have respectively assigned, the one 5 or 6, and the other 8, as the mean or average hourly number of meteors visible within one person's sphere of vision [695] on days not extraordinary. The discussion of a very large number of observations is required for the elucidation of this question, which is as important as the determination of the laws in respect to their direction. I therefore addressed myself with confidence to the already mentioned observer, Julius Schmidt, at Bonn, who, long accustomed to astronomical accuracy, has also comprehended in his labours, with the animated zeal which belongs to him, the whole of the phænomenon of meteors, of which the formation of aerolites and their precipitation or fall upon the surface of the Earth are regarded by him as only one of the phases,—the rarest, and therefore not the most important. The following are the principal results contained in the communications with which, in compliance with my request, he has favoured me [696].

"Between three and eight years of observation have given for the phænomenon of sporadic shooting stars the mean number of from 4 to 5 per hour: this is the ordinary state, as distinguished from a periodical phænomenon. The mean numbers of *sporadically* shooting or falling stars per hour, in the several months, are as follows:—

January, 3·4; February, —; March, 4·9; April, 2·4; May, 3·9; June, 5·3; July, 4·5; August, 5·3; Sep-

tember, 4·7; October, 4·5; November, 5·3; December, 4·0.

In *periodical* falls of meteors we may expect, on the average, from 13 to 15 in each hour. For a single period, that of August,—the stream of St. Lawrence,—we find on the mean of from 3 to 8 years of observation, the following gradual increase of numbers from the ordinary sporadical, to the extraordinary periodical, phænomenon :—

| Time. | Number of Meteors per Hour. | Number of Years of Observation. |
|---|---|---|
| 6th August | 6 | 1 |
| 7th ,, | 11 | 3 |
| 8th ,, | 15 | 4 |
| 9th ,, | 29 | 8 |
| 10th ,, | 31 | 6 |
| 11th ,, | 19 | 5 |
| 12th ,, | 7 | 3 |

August of the last year, 1851, (a single year therefore) gave per hour, notwithstanding the bright moonlight,—

| | |
|---|---|
| 7th August | 3 meteors. |
| 8th ,, | 8 ,, |
| 9th ,, | 16 ,, |
| 10th ,, | 18 ,, |
| 11th ,, | 3 ,, |
| 12th ,, | 1 meteor. |

According to Heis, there were observed, on the 10th of August—

| | | |
|---|---|---|
| In 1839, in 1 hour | . . . . . . | 160 meteors. |
| In 1841 „ | . . . . . . | 43 „ |
| In 1848 „ | . . . . . . | 50 „ |

In 1842 there fell, in the August stream of meteors, at the time of the maximum of the phænomenon, 34 shooting stars in 10 minutes. All these numbers refer to the sphere of vision of one observer. Since 1838, the November falls have been less remarkable. (However, on the 12th of November, 1839, Heis still counted from 22 to 35 meteors per hour; and on the 13th November, 1846, from 27 to 33.) So much do the streams of meteors differ in abundance in particular years. The number of falling meteors is, however, always considerably greater at those periods than in ordinary nights, which shew only 4 or 5 sporadically shooting stars in an hour. It is in January (reckoning from the 4th), in February, and in March, that meteors appear to be most rare" (697).

"Although the August and November periods are, with reason, the most remarked, yet, since falling stars have been observed with greater watchfulness and exactness, both in regard to number and parallelism, five other periods have also been recognised:—

*January:* the two or three first days, from the 1st to the 3d; still somewhat doubtful.

*April:* 18th or 20th? previously conjectured by Arago. Great streams occurred on the 25th of April, 1095; 22d April, 1800; 20th April, 1803 (Kosmos, Bd. i. S. 404; Engl. ed. p. xxix. Note 74; Annuaire pour 1836, p. 297).

*May:* 26th?

*July:* 26th to 30th; Quetelet. Maximum more particularly between the 27th and 29th July. The lamented Edouard Biot found from the oldest Chinese observations a general maximum between the 18th and 27th of July.

*August:* but prior to the stream of St. Lawrence, and particularly between the 2d and 5th of the month. For the most part no regular increase is observed from the 26th of July to the 10th of August.

——— The "August period," or "stream of St. Lawrence" itself; Muschenbroeck and Brandes (Kosmos, Bd. i. S. 130 and 403; English edit. pp. 114 and xxviii. Notes 71 and 73). A decided maximum on the 10th of August observed for many years. (An ancient tradition prevails in Thessaly, in the mountainous districts around Mount Pelion, that during the night of the Feast of the Transfiguration, on the 6th of August, the heavens open, and lights, or candles, *κανδήλια*, appear in the midst of the opening. Herrick, in Silliman's Amer. Jour. Vol. xxxvii. 1839, p. 337; and Quetelet, in the Nouv. Mém. de l'Acad. de Bruxelles, T. xv. p. 9.)

*October:* the 19th and about the 26th. Quetelet; Boguslawski in the "Arbeiten der schles. Gesellschaft für vaterl. Cultur," 1843, S. 178; and Heis, S. 33. Heis brings together observations of the 21st Oct. 1766, 18th Oct. 1838, 17th Oct. 1841, 24th Oct. 1845, 11th—12th Oct. 1847, and 20th—26th Oct. 1848. (On the three October phænomena in the years 902, 1202, and 1366, see Kosmos, Bd. i. S. 133 and 398; English edit. p. 118 and p. xxiv.) The conjecture of Boguslawski, that the Chinese meteor-swarms of 18th—27th July, and the great fall of shooting stars of 1366,

on the 21st October (Old Style), were the August and November periods which have now moved forward, loses much of its weight by the considerable amount of new experience gained from 1838 to 1848 ([698]).

*November:* 12th to 14th day; very rarely the 8th or 10th. The great fall of meteors at Cumana, 11th—12th November, 1799, which was described by Bonpland and myself, so far gave occasion to the belief in periodically returning phænomena on determinate days, that when the similarly great meteor-fall of 1833 (Nov. 12th—13th) took place, the phænomenon of 1799 was remembered ([699]).

*December:* 9th—12th; but, according to Brandes' observation, Dec. 6th—7th, in 1798; Herrick, in Newhaven, 1838, Dec. 7th—8th; Heis, 1847, Dec. 8th and 10th.

These eight or nine epochs of periodical streams of meteors, of which the last five are the best assured, are here recommended to the diligence of observers. Not only do the streams differ from each other in different months, but also the abundance and brightness of the same stream differ strikingly in different years.

"The upper limit of the height above the Earth of falling stars cannot be accurately made out, and Olbers already regarded all heights of above 30 German, or 120 English geographical miles, as very uncertainly determined. The lower limit, formerly assigned as usually about 16 miles (or upwards of 95000 feet), must be considerably diminished. Some are found by measurement to descend almost as low as the summits of Chimborazo and Aconcagua, or to within

4 geographical miles of the level of the sea. On the other hand, Heis remarks that, by exact calculation, a shooting star seen on the 10th of July, 1837, simultaneously at Berlin and at Breslau, shone out first at an elevation of 62 German, or 248 English miles, and disappeared at the height of 42 German, or 168 English miles: other shooting stars, on the same night, vanished at the height of 56 English geographical miles. From the older investigation of Brandes (1823), it followed that out of 100 shooting stars seen and well measured from two stations, 4 had an elevation of only from 4 to 12 English geographical miles, 15 between 12 and 24; 22 between 24 and 40; 35 (about one-third of the whole number) between 40 and 60; 13 between 60 and 80; and only 11 (about one in ten of the whole) above 80, these being, indeed, mostly between 180 and 240 English geographical miles. The inferences in respect to the colour of shooting stars, derived from a collection of 4000 observations, extending over 9 years, were: that $\frac{2}{3}$ are white, $\frac{1}{7}$ yellow, $\frac{1}{17}$ orange, and only $\frac{1}{37}$ green."

Olbers remarked that, at Bremen, during the fall of meteors in the night of the 12th—13th November, 1838, there was a fine Aurora Borealis, which covered a large portion of the heavens with a vivid blood-red light; and that the falling stars which shot across this region preserved their whiteness unimpaired. Hence it may be inferred that the beams of the Aurora were further from the Earth than the shooting stars, when these last became invisible in their fall (Schum. Astr. Nachr. No. 372, S. 178).

The relative velocity of motion of shooting stars has hitherto been estimated at from $4\frac{1}{2}$ to 9 German, or 18 to 36 English geographical miles in a second; while the Earth

has only a velocity of translation of 4·1 German, or 16·4 English geographical miles (Kosmos, Bd. i. S. 127 and 400; English edit. p. 112 and xxv. Note 68). Corresponding observations by Julius Schmidt, at Bonn, and Heis, at Aix-la-Chapelle, in 1849, gave, indeed, as the minimum velocity of a shooting star, which was seen at a perpendicular height of 48 miles above St. Goar, and moved in the direction of the Lake of Laach, only 14 English geographical miles. According to other observations of the same observers, and of Houzeau at Mons, however, the velocity of four shooting stars was found between 46 and 95 English geographical miles in a second, therefore twice and five times as great as the planetary velocity of the Earth. The strongest evidence of a cosmical origin is afforded by this result, taken in connection with the circumstance that periodical shooting stars continue for several hours to proceed, independently of the Earth's rotation, from one and the same star, although the direction of the star may not be that towards which the Earth is then moving.

According to existing measurements, balls of fire appear on the whole to move more slowly than shooting stars. When meteoric stones drop from fire-balls, it is deserving of remark to how small a depth they sink into the ground. The mass, weighing 276 pounds, which fell on the 7th of November, 1492, at Ensisheim, in Alsace, only penetrated to a depth of about 3 feet; and the same was the case with the aerolite of Braunau, on the 14th of July, 1847. I only know of two meteoric stones which tore up the loose soil to a depth respectively of 6 and 18 feet; the aerolite of Castro Villari, in the Abruzzi, of the 9th of February, 1583, and

that of Hradschina, in the Agram district, 26th of May, 1751.

The question whether, in shooting stars, any substance falls to the earth, has been much discussed, and opposite opinions have been entertained. The straw-thatched roofs of the Commune of Belmont (Departement de l'Air, Arrondissement Belley), which were set on fire by a meteor on the night of the 13th of November (the epoch, therefore, of the November phænomenon), were ignited, it would appear, not by the fall of a shooting star, but by a bursting fire-ball, which, from the account given by Millet d'Aubenton, is supposed, (though this is uncertain,) to have let fall aerolites. A similar conflagration, occasioned by a ball of fire, happened on the 22d of March, 1846, at 3 in the afternoon, in the Commune de St-.Paul, near Bagnère de Luchon. The fall of stones which took place at Angers on the 9th of June, 1822, was, on the other hand, attributed to a fine shooting star seen near Poitiers. This phænomenon, which has not been described with sufficient fulness, deserves the greatest consideration. The falling star in question resembled much what are called Roman Candles in fireworks. It left behind a straight train or streak, very narrow in the upper, and very broad in the lower part; of great brightness, and lasting ten or twelve minutes. Sixty-eight miles north of Poitiers an aerolite fell, accompanied by loud detonations.

Do the substances of which the shooting stars consist always burn or consume in the outermost strata of the atmosphere, whose refracting power is shewn by the phænomena of twilight? The different colours exhibited, as mentioned above, during the process of combustion, appear to

indicate chemical diversity of substance. The form of these igneous meteors is also extremely variable: some appear only as phosphoric lines, and these so slender and numerous, that Forster, in the winter of 1832, saw the sky appear illuminated by them, as if covered by a faintly shining veil (700). Many shooting stars move merely as shining points, and leave no tail or train behind. The continued burning shewn in the more rapid or slower disappearance of the trains, which are usually many miles in length, is the more remarkable, because the burning train sometimes bends into a curve, and makes but little progressive movement. The circumstance observed by Admiral Krusenstern and his companions during their voyage of circumnavigation, of the luminosity continuing for some hours of the train of a fireball which had itself long disappeared, recalls vividly to our remembrance the "long shining" of the cloud from which, according to the not indeed altogether trustworthy narration of Damachos, the aerolite of Ægos Potamoi is supposed to have fallen (Kosmos, Bd. i. S. 395 and 407; English edit. pp. xxi. and xxxii. Notes 60 and 87).

There are shooting stars of very different magnitudes, their apparent diameters sometimes increasing until they are equal to that of Jupiter or Venus. In the fall of shooting stars at Toulouse, 10th April, 1812, and on the occasion of a ball of fire observed at Utrecht on the 23d of August of the same year, a body of large dimensions was seen to accrue, as it were, from a luminous point, first shooting upwards with the appearance of a star, and then expanding into a globe equal to the apparent magnitude of the Moon. In very abundant falls of meteors, as in those of 1799 and 1833, many fire-balls were undoubtedly inter-

spersed among thousands of shooting stars; but the identity of these two kinds of igneous meteors is nevertheless, as yet, by no means proved. Affinity is not identity. There still remains much to be investigated in the physical relations of both these classes;—as also respecting the effect, remarked by Admiral Wrangel on the shores of the Icy Sea [701], produced by shooting stars on the development of the Aurora Borealis;—and the many vaguely described, indeed, but not therefore to be hastily denied, luminous processes which appear to have preceded the formation of some fire-balls. In the greater number of cases, balls of fire have appeared unaccompanied by falling stars; and there has been nothing periodical in the phænomenon. What we know of shooting stars, in respect to their radiation from particular points, can for the present only be applied with great caution to fire-balls.

Meteoric stones fall, in very rare cases, with a perfectly clear sky without the previous formation of a black meteor-cloud, and without any luminous phænomena being seen, but with a loud and terrible crashing sound, as at Klein Wenden, not far from Mühlhausen, on the 16th of September, 1843;—or, which is a less rare case, they are hurled from a suddenly formed dark cloud, accompanied with phænomena of sound, but without light;—and lastly, and this is the most frequent case, the fall of meteoric stones takes place in close connection with bright fire-balls. Well-described and indubitable examples of this connection are afforded by the falls of stones at Barbotan (Dep. des Landes), on the 24th of July, 1790, accompanied by the appearance, at the same time, of a red ball of fire and a small *white* meteoric cloud [702], from which the aerolites fell; the

fall of a stone at Benares, in Hindostan, on the 13th of December, 1798; and that which took place at Aigle, in the Departement de l'Orne, on April 26th, 1803. This last-named phænomenon — which, of all those that have been enumerated, is the one which has been most carefully examined and described (by Biot), and which occurred twenty-three centuries after the fall of the great stone in Thrace, and three centuries after a friar had been killed by an aerolite at Crema (703),—finally prevailed over the scepticism which appears to be indigenous in academical bodies. The following is the description of the phænomenon of 1803:—At Alençon, Falaise, and Caen, at 1 P.M., a large ball of fire was seen moving from S.E. to N.W., with an everywhere perfectly clear sky. A few moments later, at Aigle, an explosion lasting five or six minutes was heard, taking place in a dark, almost motionless, very small cloud: it was followed by three or four detonations like cannon-shots, and by a noise resembling the fire of small arms and the roll of many drums. At each explosion some of the vapours forming the small dark cloud were seen to detach themselves and float away. At this place no luminous phænomena were perceived. At the same time there fell, on an elliptically shaped piece of ground, of which the major axis, running from S.E. to N.W., was nearly five English miles in length (1·2 German geographical mile), many meteoric stones, of which the largest weighed 17½ pounds. The stones were hot, but not red hot (704), smoked sensibly, and, which is a very striking circumstance, were more easily broken in the few first days after their fall than subsequently. I have purposely dwelt the longer on this phænomenon, because I wish to compare it with one

which took place on the 13th of September, 1768. On that day, at half-past four in the afternoon, near the village of Luce (Departement de l'Eure et Loire), four miles west of Chartres, a dark cloud was seen, and there was heard to come from it a noise like a cannon-shot, followed immediately afterwards by a hissing in the air, occasioned by the fall of a black stone moving in a curve. The fallen stone, which was half sunk in the earth, weighed 7½ pounds, and was so hot that it could not be touched. It was analysed, but only in a very imperfect manner, by Lavoisier, Fougeroux, and Cadet. So far as was perceived the whole occurrence was unaccompanied by any luminous phænomena.

As soon as periodical falls of shooting stars became an object of observation, so that on particular nights their appearance was watched and waited for, it was remarked that the frequency of meteors increased with increasing time from midnight, and that the greatest number fell between 2 and 5, A.M. Even in the great fall of meteors at Cumana in the night of the 11th to 12th of November, 1799, my travelling companion had seen the greatest abundance of shooting stars between the hours of 2½ and 4 A.M. A very meritorious observer of these phænomena, Coulvier-Gravier, presented an important memoir "Sur la variation horaire des étoiles filantes," to the Institut of Paris, in May 1845. It is very difficult to divine the reason of such an "horary variation," or why the distance from midnight should influence these phænomena. If it should be established that, under different meridians, shooting stars are not seen in their greatest abundance until a certain determinate period between midnight and day-break, we should have to assume, together with a cosmical origin, the not very probable

hypothesis that these hours of the night, or rather of the early morning, are peculiarly favourable to the "ignition," or luminousness, of falling stars; those which shoot in the hours before midnight remaining more often invisible. We must long continue to persevere in collecting observations. The principal characteristics of the solid masses which fall from the atmosphere, both as respects their chemical relations, and their granular texture which has been examined more particularly by Gustav Rose, have been treated by me in my first volume (Kosmos, Bd. i. S. 133—137; English edit. p. 119—122) with I believe tolerable completeness, according to the state of our knowledge at that time (1845). The successive labours of Howard, Klaproth, Thénard, Vauquelin, Proust, Berzelius, Stromeyer, Laugier, Dufresnoy, Gustav and Heinrich Rose, Boussingault, Rammelsberg, and Shepard, have supplied a rich harvest (705); but it may not be inappropriate to remember, that probably two-thirds of the meteoric stones which have fallen are hidden from us in the depths of the sea. Although aerolites from all zones, and from the most widely dispersed places,—in Greenland, Mexico, and South America, Europe, Siberia, and Hindostan,—exhibit an obvious physiognomic similarity, when examined more closely they are also found to present great diversities. Some contain 96 per cent. of iron, others (Siena) scarcely 2 per cent. Almost all have a thin, black, shining, and at the same time somewhat veined, crust or coating; but in one (that of Chantonnay), this crust was entirely wanting. The specific weight of some meteoric stones is as great as 4·28, while in the carbonaceous stone of Alais, consisting of friable lamellæ, it was found to be only 1·94. Some (Juvenas) have a texture resembling that

of dolerite, in which crystallised olivine, augite, and anorthite, can be severally recognised; others (as the mass of Pallas) shew merely iron, containing nickel and olivine; while others again (judging by the relative proportions of the ingredients) are aggregates of hornblende and albite (Chateau-Renard), or of hornblende and labradorite (Blansko and Chantonnay).

According to a general review of the results which have been derived by Professor Rammelsberg,—an acute chemist, who has recently occupied himself uninterruptedly, with equal activity and success, with the analysis of aerolites, and with their composition from simple minerals,—"the distinction of masses which have fallen from the atmosphere into two classes—viz. meteoric iron and meteoric stones—is not to be taken rigidly and absolutely. We find, although rarely, meteoric iron with intermingled silicates, (in the Siberian mass of 1270 Russian pounds, which has been reweighed by Hess, there are interspersed grains of olivine);—and, on the other hand, many meteoric stones contain metallic iron.

"*A.* Meteoric iron,—the fall of which has only in a few cases been actually observed by eye-witnesses (Hradschina, Agram, 26th of May, 1751; and Braunau, 14th of July, 1847), while the greater number of analogous masses have remained long on the surface of the ground,—has in general very similar physical and chemical qualities. It almost always contains, in finer or coarser particles, a sulphuret of iron, which does not, however, appear to be either iron pyrites or magnetic pyrites, but proto-sulphuret of iron (706). The principal mass in such cases does not consist of a pure metallic iron; it is formed rather of an alloy

of iron and nickel: so that the presence of the nickel, which is a constant ingredient (on an average 10 per cent., sometimes rather more, and sometimes rather less), is justly regarded as an excellent criterion of the meteoric character of the entire mass. It is simply an alloy of two isomorphous metals, not a combination in definite proportions. We also find intermixed in smaller quantities cobalt, manganese, magnesium, tin, copper, and carbon. The last-named substance is partly mechanically interspersed in the form of graphite difficult of combustion, and partly chemically combined or united with iron; analogous, therefore, to much bar-iron. A mass of meteoric iron also always contains a peculiar combination of phosphorus with iron and nickel, which substances, on dissolving the iron in hydrochloric acid, remain behind in the form of microscopic crystalline needles and lamellæ of a silvery whiteness."

"*B.* Meteoric stones, more strictly so called,—are usually divided, according to their external appearance, into two classes. In one of these, the apparently homogeneous and principal portion of the mass shews interspersed grains and spangles of meteoric iron, which are attracted by a magnet, and are quite similar in their nature to meteoric iron, found by itself in larger masses. To this class belong, for example, the stones of Blansko, Lissa, Aigle, Ensisheim, Chantonnay, Klein Wenden near Nordhausen, Erxleben, Chateau-Renard, and Utrecht. The other class is free from metallic intermixtures, and presents rather a crystalline assemblage or mixture of different mineral substances; as, for example, in the stones of Juvenas, Lontalax, and Stannern."

After the first chemical examinations of meteoric stones made by Howard, Klaproth, and Vauquelin, the possibility

of their consisting of an assemblage of distinct combinations was for a long time not adverted to; their component parts were examined only generally, and it was thought sufficient to remove by means of a magnet any metallic iron which might be contained in them. After Mohs had drawn attention to the analogy of some aerolites with certain telluric kinds of rock, Nordenskjöld attempted to shew that olivine, leucite, and magnetic iron, were the constituent parts of the aerolite of Lontalax, in Finland; but the fine observations of Gustav Rose have shewn beyond a doubt that the meteoric stone of Juvenas consists of magnetic pyrites, augite, and a feldspar which has much resemblance to labradorite. Berzelius was thus led to examine by chemical methods the mineral nature of the several combinations in the aerolites of Blansko, Chantonnay, and Alais (Kongl. Vetenskaps Academiens Handlingar för 1834). The path thus happily indicated by Berzelius has been since extensively pursued.

"*a*. The first and more numerous class of meteoric stones, viz. those with metallic iron, contain this substance, sometimes in minute interspersed particles, and sometimes in larger masses, which occasionally even form, as it were, a connected iron skeleton, thus constituting a transitional link with those masses of meteoric iron in which, as in the Siberian mass of Pallas, other substances are not found. The olivine which they always contain causes them to be rich in magnesia, and is itself the ingredient which is decomposed when these meteoric stones are treated with acids. Like the telluric olivine it is a silicate of magnesia and protoxide of iron. The part of the stones which is not attacked by acids is a mixture of feldspatic and augitic substances, the nature of which can only be determined by calculation from

the whole of the mixture (as labradorite, hornblende, augite, or oligoklas).

"β. The second, much rarer, class of meteoric stones has been less examined. These stones sometimes contain magnetic iron, olivine, and some feldspatic and augitic substances; and sometimes they consist merely of the two last mentioned simple minerals, and the feldspar is then represented by anorthite ([707]). Chromate of iron (protoxide of iron, oxide of chromium) is found in small quantities in almost all meteoric stones: phosphoric acid and titanic acid, discovered by Rammelsberg in the remarkable stone of Juvenas, may perhaps indicate the presence of apatite and titanite.

"The simple substances which have as yet been shewn to exist in meteoric stones are the following:—Oxygen, sulphur, phosphorus, carbon, silicon, aluminum, magnesium, calcium, potassium, sodium, iron, nickel, cobalt, chrome, manganese, copper, tin, and titanium; being in all 18 substances ([708]). The more immediate components are—*a*, metallic: an alloy of nickel and iron, a compound of phosphorus with iron and nickel, sulphide of iron, and magnetic pyrites;—*b*, oxydised: magnetic iron and chromate of iron;—*c*, silicates: olivine, anorthite, labradorite, and augite."

It would still remain for me, with the view of concentrating in this place the greatest possible number of important facts, taken apart from hypothetical anticipations, to point out the many analogies which some meteoric stones present, if regarded as rocks, with the older trap rocks (dolerites, diorites, and melaphyres), and to basalts and more recent

lavas. These analogies are the more striking, because the "metallic alloy of nickel and iron, which is constantly contained in certain meteoric masses," has not hitherto been discovered in telluric minerals. The same distinguished chemist of whose friendly communications I have availed myself in the last few pages, has enlarged upon this subject in a separate treatise (709), the results of which will be more appropriately noticed in the geological portion of the Cosmos.

## Conclusion.

In concluding the Uranological portion of the physical description of the Universe, and casting a retrospective glance on what has been attempted,—I will not say accomplished,—I feel it necessary, after the execution of so difficult an undertaking, to remind my readers afresh, that its accomplishment was only possible under the conditions which were indicated in the introduction to the third volume. The attempted cosmical treatment of Uranology is limited in its design to the presentation or description of what we know of the celestial spaces and the matter by which they are occupied, whether agglomerated into spheres, or existing in an uncondensed or unagglomerated form. The work undertaken is, therefore, in its nature essentially distinct from the more comprehensive meritorious works on astronomy in the different literatures of the present time. Astronomy itself, regarded as a science, and as the triumph of mathematical combination, based on the secure foundation of the doctrine of gravitation, and on the degree of perfection attained by the higher analysis as the intellectual instrument of investigation, treats of the phænomena of motion, as measured by time and space; of the locality or position of the celestial bodies in their continually varying

relations to each other; of changes of form, as in tailed comets; and changes of light, amounting even to new apparition and entire extinction of light in distant suns. The quantity of existing matter in the Universe remains, it is believed, always the same; but, according to what has been already investigated of the physical laws of nature in the *telluric* sphere, we there see ever recurring, as if ever unsatisfied, *change* ceaselessly prevailing in countless and indescribable combinations, in the perpetual circle of the permutation of substances. This manifestation of force or power in matter is called forth by its, at least apparent, elementary heterogeneity. Exciting motion in portions of space immeasurably small, the heterogeneity of substances complicates all problems relating to terrestrial processes of nature.

Astronomical problems are more simple in their character. Celestial mechanics, as yet free from the complications alluded to, and directed to considerations relative to the quantity of ponderable matter, *i. e.* to mass, and to light- and heat-exciting undulations, have, by reason of this simplicity, in which everything can be reduced to motion, remained amenable throughout to mathematical treatment. It is this advantage which gives to treatises on theoretical astronomy a great and peculiar charm. There is reflected in them what the mental labour of the last few centuries has achieved by analytical methods: we see in them how forms and orbits have been determined; how, in the phænomena of the motions of the planets, small fluctuations take place round a mean state of equilibrium; and how the preservation and permanence of the planetary system are provided for by its internal structure, and by the equilibrium of mutually compensating perturbations.

The examination of the means, or methods, by which we have thus arrived at the comprehension of the Universe, and the explanation of the intricate phænomena of the heavens, do not belong to the plan of the present work. The "Physical Description of the Universe" tells of the contents of space, and of the organic life which animates it, in the two spheres of uranologic and telluric relations. It dwells on the discovered laws of nature, and treats them as facts achieved and ascertained,—as the direct results of empirical induction. In order that a work on the Cosmos might be executed within its appropriate limits, and without acquiring an immoderate extension, it was necessary that it should not attempt to propound theoretically the bases of the connection of phænomena. In the view of this limitation of the proposed plan, I have devoted the more diligent care, in this astronomical volume of the Cosmos, to the several facts and to the order of their arrangement. From the consideration of cosmical space, *i. e.* its temperature, its degree of transparency, and the resisting medium which fills it, I have proceeded to the subjects of natural and telescopic vision; the limits of visibility; the velocity of light according to its different sources; our imperfect measurements of the intensity of light; and the new optical means of discriminating between direct and reflected light. Then follow,—the heaven of the fixed stars; the numbers of its self-luminous suns, so far as their positions are known to us, and their probable distribution; the variable stars which have well-measured periods; the proper motions of the fixed stars; the hypothesis of the existence of dark bodies, and their influence on the motions of double stars; and

lastly nebulæ, so far as these are not remote and very dense clusters of stars.

The transition from the sidereal portion of Uranology,—from the heaven of the fixed stars,—to our solar system, is only the transition from the universal to the particular. In the class of double stars, self-luminous cosmical bodies move round a common centre of gravity: in our solar system, which is composed of very heterogeneous elements, dark cosmical bodies revolve around a self-luminous one, or rather round a common centre of gravity which is sometimes within and sometimes without the circumference of the central body. The several members of the solar domain are more dissimilar in their nature than for many centuries there had been reason to suppose. They divide themselves into primary planets, and secondary ones or satellites, the primary planets having among them a group in which the orbits intersect each other;—an unascertained number of comets;—the ring of the zodiacal light;—and, with great probability, the periodic meteor-asteroids.

It still remains to state expressly the three great laws discovered by Kepler, in their actual application to the motions of the planets. First law: Every path of a planetary body is an ellipse, having the Sun in one of its foci. Second law: Every planetary body describes round the Sun equal areas in equal times. Third law: the squares of the periodic times of revolution of two planets are to each other as the cubes of their mean distances. The second of these laws is sometimes called the first, because it was discovered earlier than the others. (Kepler, Astronomia nova, seu Physica cœlestis, tradita commentariis de motibus stellæ Martis, ex

observ. Tychonis Brahi elaborata, 1609: compare cap. xl. with cap. lix.) The two first laws would be applicable if there were only one single planetary body in existence; the third and most important of the three, which was discovered nineteen years later than the other two, determines the law of the motions of two planets. (The manuscript of the Harmonice Mundi, which was published in 1619, was completed on the 27th of May, 1618.)

If the laws of the planetary motions were empirically discovered in the beginning of the 17th century, and if Newton first unveiled the force from whose action Kepler's laws must be regarded as necessary consequences, the end of the 18th century, through the new paths opened to the investigation of astronomical truths by the improvement of the infinitesimal calculus, has the merit of having demonstrated the "stability of the planetary system." The principal elements of this stability are, the invariability of the major axes of the planetary orbits demonstrated by Laplace (1773 and 1784), Lagrange, and Poisson; the long periodical variation, restricted within narrow limits, of the excentricities of two large and remote planets, Jupiter and Saturn; the distribution of the masses, since the mass of Jupiter itself, the greatest of all the planetary bodies, is only $\frac{1}{1048}$ of that of the all-controlling central body; and lastly, the arrangement, that by the primordial plan of creation, and by the mode of their origination, all the planets of the solar system move in one direction both in regard to translation and to rotation, in orbits of small and little-varying ellipticity, and in planes having only moderate differences of inclination; and that the periods of revolution of the different planets have no common measure.

These elements of stability, elements as it were of the preservation and continuance of the "life" of the planets, are attached to the condition of mutual action within the interior of a circumscribed circle. If by the arrival from the regions of exterior space of a cosmical body not previously belonging to the system, this condition cease (Laplace, Expos. du Syst. du Monde, p. 309 and 391), then, indeed, there might ensue, as the result either of new forces of attraction or of a shock, consequences injurious or destructive to that which now exists, until at last, after a long conflict, a new equilibrium should be produced. The consideration of the possible arrival of a comet in a hyperbolic path from remote regions, even though the smallness of its mass should be compensated by an enormous velocity, could only occasion uneasiness to an imagination which should be inaccessible to the reassuring deductions of the calculus of probabilities. Those travelling clouds, the interior comets of our system, are as far from being dangerous to the stability of the system, as are he great inclinations of the orbits of some of the small planets situated between Mars and Jupiter. That which must be designated as a mere *possibility* lies beyond the domain of a Physical Description of the Universe. Science ought not to pass from its true domain into the misty land of cosmological dreams.

## RECTIFICATIONS AND ADDITIONS TO THIS VOLUME.

### Pages 35—36.

See Editor's Note at the foot of p. 36.

### Pages 55—56.

The singular phænomenon of the apparently fluctuating motion of a star has been recently observed again. It was seen by very trustworthy witnesses at Trèves, on the 20th of January, 1851, between 7 and 8 in the evening. The star was Sirius, and was near the horizon at the time. See the letter of the Head Master of Mathematics, Herr Flesch, in Jahn's Unterhaltungen für Freunde der Astronomie.

### Pages 112 and lix., Note (216).

The lively wish which I had expressed, to be enabled to trace with more certainty the historical epoch within which the disappearance of the red colour of Sirius falls, has been in part fulfilled by the honourable diligence of a young savant, Dr. Wöpcke, who combines great acquaintance with the Oriental languages with distinguished mathematical knowledge. This gentleman, the translator of, and commentator on, the important "Algebra" of Omar

Alkhayyami, writes to me from Paris, in 1851, as follows:—"The wish expressed by you in the astronomical volume of Kosmos, has led me to examine four manuscripts of the Uranography of Abdurrahman Al-Ssufi, which are here; and I have found that α Bootis, α Tauri, α Scorpii, and α Orionis, are all expressly termed 'red:' Sirius, on the contrary, has no such epithet applied to it. The passage relating to Sirius is in all the four manuscripts to the same effect, viz. that 'the first of these stars' (in Canis Major) 'is the large bright star in the mouth, which is marked on the Astrolabe, and is called Al-je-maanijah.'" Does it not appear probable from this examination, and from what I cited from Alfragani (Note [216]) that the change of colour of Sirius took place intermediately between the epoch of Ptolemy and that of the Arabian astronomers?

## Pages 191—192.

In the brief exposition of the method of finding the parallax of double stars by the velocity of light, it should have been said, that the interval of time which elapses between the moments when the planetary or secondary star is nearest to, and farthest from, the Earth, is always longer when the change is from the greatest proximity to the greatest distance, than in the inverse case, when the change is from the greatest distance to the greatest proximity.

## Page 214.

In the French translation of the astronomical volume of Kosmos (Part I.), which I have rejoiced to see undertaken by Monsieur Faye, that highly-informed astronomer has greatly

enriched the section on double stars. I had unduly omitted to make use of the important labours of Monsieur Yvon Villarceau, which had been read to the French Institut in 1849 (Connaissance des temps pour l'an 1852, p. 3—128). I borrow here, from a table given by M. Faye of the elements of the orbits of eight double stars, the four first stars, which he believes to be the most securely calculated.

ELEMENTS OF THE ORBITS OF DOUBLE STARS.

| Names and Magnitudes of the Double Stars. | Semi-major Axis. | Excentricity. | Periods of revolution in years. | Names of the Computers. |
|---|---|---|---|---|
| ξ Ursæ majoris (4 and 5, Groombridge.) | ″ 3·857<br>3·278<br>2·295<br>2·439 | 0·4164<br>0·3777<br>0·4037<br>0·4315 | 58·262<br>60·720<br>61·300<br>61·576 | Savary ...... 1830<br>J. Herschel... 1849<br>Mädler ...... 1847<br>Y. Villarceau. 1848 |
| p Ophiuchi (4 and 6, Gr.) | 4·328<br>4·966<br>4·8... | 0·4300<br>0·4445<br>0·4781 | 73·862<br>92·338<br>92·.... | Encke......... 1832<br>Y. Villarceau. 1849<br>Mädler ...... 1849 |
| ζ Herculis (3 and 6·5, Gr.) | 1·208<br>1·254 | 0·4320<br>0·4482 | 30·22<br>36·357 | Mädler ...... 1847<br>Y. Villarceau. 1847 |
| η Coronæ (5·5 and 6, Gr.) | 0·902<br>1·012<br>1·111 | 0·2891<br>0·4744<br>0·4695 | 42·50<br>42·501<br>66·257 | Mädler ...... 1847<br>Y. Villarceau. 1847<br>The same, 2d solution. |

The problem of the period of revolution of η Coronæ has two solutions: one being 42·5, and the other 66·3 years; but the latest observations of Otto Struve assign the preference to the second result. Mons. Ivon Villarceau finds for the semi-major axis, excentricity, and period of revolution expressed in years, of three other double stars, as follows:—

| | | | |
|---|---|---|---|
| γ Virginis . . | 3″·446 | 0·8699 | 153·787 |
| ζ Cancri . . . | 0″·934 | 0·3662 | 58·590 |
| α Centauri . . | 12″·128 | 0·7187 | 78·486 |

I have termed the occultation of one fixed star by another, (in the case of ζ Herculis), "apparent" (p. 212). Mons. Faye shows that it is a consequence of the factitious diameter of stars as seen in our telescopes (Kosmos, Bd. iii. S. 67 und 167; Engl. ed. p. 50 and 110).—The parallax of 1830 Groombridge, which I have given in S. 275 (Engl. ed. p. 190) at 0″·226, has been found by Schlüter and Wichmann at 0″·182, and by Otto Struve at 0″·034.

## Page 371.

It was not until the section upon the small planets had been printed off that we received in the North of Germany the information of the discovery of a fifteenth small planet, Eunomia, by De Gasparis, on the 19th of July, 1851. The elements of Eunomia, computed by G. Rümker, are:—

| | |
|---|---|
| Epoch of mean longitude . | 1851, Oct. 10, M. Green. Time. |
| Mean longitude . . . . . . | 321° 25′ 29″ |
| Longitude of perihelion . . | 27 35 38 |
| Longitude of ascending node . | 293 52 55 |
| Inclination . . . . . . . | 11 43 43 |
| Excentricity . . . . . . | 0·188402 |
| Semi-major axis . . . . . | 2·64758 |
| Mean diurnal motion . . . | 823″·630 |
| Period of revolution . . . | 1574 days. |

Pages 388—390.

By a kind communication from Sir John Herschel, dated 8th Nov. 1851, I learn that Mr. Lassell observed distinctly on the 24th, 28th, and 30th of October, and on the 2d of November, 1851, two satellites of Uranus, which appear to be still nearer to the planet than the first satellite of Sir William Herschel, to which that astronomer ascribed a period of revolution of about 5 days 21 hours, but which has not been subsequently recognised. The periods of revolution of the two satellites now seen by Lassell were about 4 days and $2\frac{1}{2}$ days.

# NOTES.

# NOTES.

(1) p. 4.—Kosmos, Bd. i. S. 56—59 and 141 (English edition, Vol. i. p. 50—53 and 126).

(2) p. 6.—Kosmos, Bd. i. S. 6—8; Bd. ii. S. 10—12 and 92 (English edition, Vol. i. p. 6—7; Vol. ii. p. 9—11 and 89).

(3) p. 6.—Kosmos, Bd. ii. S. 26—31 and 44—49 (English edition, Vol. ii. p. 24—30 and 43—48).

(4) p. 7.—Kosmos, Bd. i. S. 383—386; Bd. ii. S. 141—144 (English edition, Vol. i. p. 354—357; Vol. ii. p. 107).

(5) p. 7.—M. von Olfers, On the Remains of Animals of Gigantic Size belonging to the Ancient World, in connection with Legends of Eastern Asia, in the Abh. der Berl. Akad. 1839, S. 51. On the opinion of Empedocles respecting the cause of the destruction of the more ancient forms of animal life, vide Hegel's Geschichte der Philosophie, Bd. ii. S. 344.

(6) p. 7.—Respecting the world-tree, Ygdrasil, and the raging fountain, Hvergelmir, see Jacob Grimm's Deutsche Mythologie, 1844, S. 530 and 756; and Mallet's Northern Antiquities, 1847, p. 410, 489, and 492.

(7) p. 9.—Kosmos, Bd. i. S. 30—33 and 62—70 (English edition, p. 30—33 and 56—64).

(8) p. 10.—Kosmos, Bd. ii. S. 484 (English edition, p. 285 and xciv.)

(9) p. 10.—In the introductory Contemplations in the first volume of Cosmos (p. 33), it should not have been said generally and without exception that "the discovery of laws, and their progressive generalisation, are the objects of the experimental sciences:" a more limited sense should have been given by the introduction of the words "in many groups of phænomena." The manner in which I expressed myself in the second volume respecting the

relation subsisting between the achievements of Newton and Kepler, must, I think, show without doubt that I do not confound together the discovery of natural laws, and the interpretation, *i. e.* the explanation, of phænomena. I say of Kepler (p. 310)—"The rich supply of exact observations which were furnished by Tycho Brahe, laid the foundation of the discovery of those unchanging laws of the planetary movements which prepared for Kepler imperishable fame, and which, when *interpreted* by Newton, and shown by him to be *theoretically necessary*, were transferred to the bright domain of thought, and became the *intelligent recognition of Nature;*"—of Newton (p. 351)—"We terminate with the figure of the Earth as then recognised from theoretical considerations. Newton attained to the explanation of the system of the Universe, because he succeeded in discovering the Force of whose operation the Keplerian laws are the necessary consequences." See on this subject the excellent remarks "On Laws and Causes," contained in Sir John Herschel's Address at the Fifteenth Meeting of the British Association, held at Cambridge, 1845, p. xlii.; and the Edinburgh Review, Vol. lxxxvii. 1848, p. 180—183.

([10]) p. 11.—In the remarkable passage in which Aristotle (Metaph. xii. 8, p. 1074, Bekker) speaks of the "fragments of an early knowledge once discovered and subsequently lost," there occurs a passage of much import, indicating freedom from the Deification of natural forces or powers, personified under the forms of various divinities resembling human beings: he says—"Much has been added mythically for the sake of persuading the multitude, as well as for the support of the laws and other useful objects."

([11]) p. 11.—The important difference between these directions, τρόποι, in Natural Philosophy, is clearly indicated in Aristot. Phys. Auscult. i. 4, p. 187, Bekker. Comp. Brandis, in the Rhein. Museum für Philologie, Jahr. iii. S. 105.

([12]) p. 12.—Kosmos, Bd. i. S. 139 and 405, Note 59; Bd. ii. S. 348 and 501, Note 27 (English edition, Vol. i. p. 124, and Note 89; Vol. ii. p. 308, and Note 467). A remarkable passage of Simplicius (p. 491) opposes in the clearest manner the centripetal force to the centrifugal force: it speaks of "the heavenly bodies not falling where the centrifugal force preponderates over the proper falling force—that which draws them downwards." On the same account, in Plutarch de Facie in Orbe Lunæ, p. 923, the moon is compared, in respect to its not falling towards the Earth, to "the stone in the sling." Respecting the proper signification of the περιχώρησις of Anaxagoras, vide Schaubach, in Anaxag. Clazom. Fragm. 1827, p. 107—109.

(13) p. 12.—Schaubach, in Anaxag. Clazom. Fragm. p. 151—156 and 185—189. Plants were also supposed to be animated by the νοῦς, or mind (Aristot. de Plant. i. 1, p. 1815, Bekk.)

(14) p. 13.—On this part of the mathematical physics of Plato, compare Böckh de Platonico Syst. cœlestium globorum, 1810 et 1811; Martin, Etudes sur le Timée, T. ii. p. 234—242; and Brandis, in the Geschichte der Griechisch-Römischen Philosophie, Th. ii. Abth. i. 1844, S. 375.

(15) p. 13.—Kosmos, Bd. ii. S. 520, Note 4 (English edition, Vol. ii. Note 544). Compare Gruppe über die Fragmente des Archytas, 1840, S. 33.

(16) p. 13.—Aristot. Polit. vii. 4, p. 1326; and Metaph. xii. 7, p. 1072, 10, Bekk., and xii. 10, p. 1074, 5. The pseudo-Aristotelian book, De Mundo, which Osann ascribes to Chrysippus (Kosmos, Bd. ii. S. 14 and 106), contains also (cap. 6, p. 307) a very eloquent passage on the "Orderer and Upholder of the Universe."

(17) p. 13.—The passages which prove this are collected in Ritter's Gesch. der Philosophie, Th. iii. S. 185—191.

(18) p. 14.—Compare Aristot. de Anima, ii. p. 419. The analogy with sound is most clearly expressed in this passage; but in other parts of his writings Aristotle modified his theory of vision in various ways. Thus he says, in De Insomniis, cap. ii. p. 459, Bekker—"It is evident that vision is active as well as passive,—that the sight not only suffers, or receives as a passive recipient, something from the air (the medium of vision), but that it also acts upon the medium." He alleges as proof that, "under particular circumstances, a new and very pure metallic mirror, being looked upon by a woman, has its surface dimmed by clouded spots difficult to efface." (Compare therewith Martin, Etudes sur le Timée de Platon, T. ii. p. 159—163.)

(19) p. 14.—Aristot. de Partibus Anim., Lib. iv. cap. 5, p. 681, lin. 12, Bekker.

(20) p. 14.—Aristot. Hist. Anim., Lib. ix. cap. 1, p. 588, lin. 10—24, Bekker. "If in the animal kingdom some of the representatives of the four elements,—those, for instance, corresponding to the element of the purest fire,—are wanting upon our Earth, these intermediate steps may perhaps be present in the moon." (Biese, Die Phil. des Aristoteles, Bd. ii. S. 186). The Stagirite sought in another celestial body absent links in the chain: we find such missing intermediate gradations among ancient terrestrial forms of plants and animals which have perished.

(21) p. 14.—Aristot. Metaph. lib. xiii. cap. 3, p. 1090, lin. 20, Bekker.

(22) p. 15.—The ἀντιπερίστασις of Aristotle especially plays a great part

in all explanations of meteorological processes, as in the works—De generatione et interitu, Lib. ii. cap. 3, p. 330; Meteorologicis, Lib. i. cap. 12, and Lib. iii. cap. 3, p. 372; and in the Problems (Lib. xiv. cap. 3, Lib. viii. No. 9, p. 888, and Lib. xiv. No. 3, p. 909), which are at least drawn up according to Aristotelian principles. In the ancient hypothesis of polarity, *κατ' ἀντιπερίστασιν* similar conditions attract each other, and dissimilar conditions (+ and —) repel each other (compare Ideler, Meteorol. veterum Græc. et Rom. 1832, p. 10). "Opposite conditions, instead of neutralising tension by their combination, on the contrary increase it. The *ψυχρὸν* heightens the *θερμόν*; so also, inversely, in the formation of hail, while the cloud sinks into warmer strata of air, the surrounding warmth makes the cold body still colder." Aristotle explains by his antiperistatic process, by polarity of heat, what modern physical science explains by conduction, radiation, evaporation, and change of capacity for heat. See ingenious considerations by Paul Erman, in the Abhandl. der Berliner Akademie auf das J. 1825, S. 128.

(23) p. 15.—"All variation in natural bodies, all terrestrial phænomena, are called forth by the motion of the celestial sphere."—Aristot. Meteor. i. 2, p. 339; and De gener. et corrupt. ii. 10, p. 336.

(24) p. 15.—Aristot. de Cœlo, Lib. i. cap. 9, p. 279; Lib. ii. cap. 3, p. 286; Lib. ii. cap. 13, p. 292, Bekker. (Compare Biese, Bd. i. S. 352—357.)

(25) p. 15.—Aristot. phys. Auscult. Lib. ii. cap. 8, p. 199; De Anima, Lib. iii. cap. 12, p. 434; De Animal. generat. Lib. v. cap. 1, p. 778, Bekker.

(26) p. 16.—Aristot. Meteor. xii. 8, p. 1074; of which passage a remarkable elucidation is contained in the Commentary of Alexander Aphrodisiensis. The heavenly bodies are not soul-less matter, they are rather to be regarded as acting and living beings (Aristot. de Cœlo, Lib. ii. cap. 12, p. 292). They are the divinest of phenomena, *τὰ θειότερα τῶν φανερῶν* (Aristot. de Cœlo, Lib. i. cap. 9, p. 278; and Lib. ii. cap. 1, p. 284). In the little pseudo-Aristotelian writing, De Mundo, in which a religious tone (respecting the preserving omnipotence of God, cap. 6, p. 400) is often seen to prevail, the upper æther is also termed divine (cap. 2, p. 392). What Kepler, in the Mysterium cosmographicum (cap. 20, p. 71), fancifully terms "moving spirits"—"animæ motrices"—is the confused idea of a force (virtus) which has its principal seat in the sun (anima mundi), diminishes by distance according to the laws of light, and impels the planets in their elliptic paths. Comp. Apelt, Epochen der Gesch. der Menscheit (Epochs in the History of Mankind), Bd. i. S. 274.

(27) p. 16.—Kosmos, Bd. ii. S. 280—291 (English edition, Vol. ii. p. 243—254).

(28) p. 17.—See the ingenious and learned account of the writings of the philosopher of Nola, in the work entitled—Jordano Bruno, par Christian Bartholmèss, T. ii. 1847, p. 129, 149, and 201.

(29) p. 17.—He was burnt at Rome on the 17th of February, 1600, according to the sentence—"ut quam clementissime et citra sanguinis effusionem puniretur." Bruno was a prisoner six years under the leads at Venice, and two years in the inquisition at Rome. Undaunted and unbroken in spirit when the sentence of death was announced to him, he replied—"Majori forsitan cum timore sententiam in me fertis quam ego accipiam." When a fugitive from Italy (in 1580), he taught in Geneva, Lyons, Toulouse, Paris, Oxford, Marburg, Wittenberg (which he called the Athens of Germany), Prague, Helmstedt, where in 1589 he completed the scientific education of Duke Henry Julius, of Brunswick-Wolfenbüttel (Bartholmèss, T. i. p. 167—178), and from 1592 in Padua.

(30) p. 18.—Bartholmèss, T. ii. pp. 219, 232, and 370. Bruno collected with care the several observations respecting the great cosmical event (1572) of the sudden shining forth of a new star in Cassiopeia. The relations of his natural philosophy to that of two of his Calabrian countrymen—Bernardino Telesio and Thomas Campanella, and to the platonising Cardinal Nicolaus Krebs of Cusa (vide Kosmos, Bd. ii. S. 503; English edition, Vol. ii. p. 109),—have been much examined in modern times.

(31) p. 18.—"Si duo lapides in aliquo loco mundi collocarentur propinqui invicem, extra orbem virtutis tertii cognati corporis; illi lapides ad similitudinem duorum magneticorum corporum coirent loco intermedio, quilibet accedens ad alterum tanto intervallo, quanta est alterius *moles* in comparatione. Si Luna et Terra non retinerentur vi animali (!) aut alia aliqua æquipollente, quælibet in suo circuitu, Terra adscenderet ad Lunam quinquagesima quarta parte intervalli, Luna descenderet ad Terram quinquaginta tribus circiter partibus intervalli; ibi jungerentur, posito tamen quod substantia utriusque sit unius et ejusdem densitatis." Kepler, Astronomia nova seu Physica cœlestis de Motibus Stellæ Martis, 1609, Introd. fol. v. On the older views of gravitation, see Kosmos, Bd. ii. S. 348, 501, and 502 (English edition, Vol. ii. pp. 308, cvii. and cviii.

(32) p. 18.—"Si Terra cessaret attrahere ad se aquas suas, aquæ marinæ omnes elevarentur et in corpus Lunæ influerent. Orbis virtutis tractoriæ, quæ est in Luna, porrigitur usque ad terras, et prolectat aquas quacunque in verticem

loci incidit sub zonam torridam, quippe in occursum suum quacunque in verticem loci incidit, insensibiliter in maribus inclusis, sensibiliter ibi ubi sunt latissimi alvei oceani propinqui, aquisque spaciosa reciprocationis libertas" (Kepler, l. c.) "Undas a Luna trahi ut ferrum a magnete......" Kepleri Harmonices Mundi libri quinque, 1619, lib. iv. cap. 7, p. 162. This same work, which contains so much that is admirable, and even the basis of the important "third law" (according to which the squares of the periods of revolution of two planets are to each other as the cubes of the mean distances), is disfigured by the wildest fancies: respiration, nutrition, and vital heat of the Earth as an animal; on a soul possessed by this animal; its memory (memoria animæ Terræ); and even its imaginative powers (animæ Telluris imaginatio). Kepler was so much attached to these reveries that he even had a serious dispute with the mystic author of the Macrocosmos—Robert Fludd, of Oxford,—(said to have had a share in the invention of the thermometer)—respecting the right of priority in these views of the Earth as a living creature (Harm. Mundi, p. 252). The attraction of mass is often confounded in Kepler's writings with magnetic attraction. "Corpus Solis esse magneticum. Virtutem, quæ planetas movet, residere in corpore Solis," (Stella Martis, Pars iii. cap. 32 and 34). He gives to every planet a magnetic axis, which is always directed to the same quarter of the heavens (Apelt, Joh. Keppler's astron. Weltansicht, 1849, S. 73).

(33) p. 19.—Comp. Kosmos, Bd. ii. S. 364 and 512, Note 55 (English edition, Vol. ii. p. 323, and Note 495).

(34) p. 19.—La Vie de M. Des-Cartes (par Baillet), 1691, P. i. p. 197 and Œuvres de Descartes publiées par Victor Cousin, T. i. 1824, p. 101.

(35) p. 20.—Lettres de Descartes au P. Mersenne du 19 Nov. 1633 et du 5 Janvier 1634 (Baillet, P. i. p. 244—247).

(36) p. 20.—The Latin translation is entitled, Mundus, sive Dissertatio de Lumine ut et de aliis Sensuum Objectis primariis. See R. Descartes, Opuscula posthuma physica et mathematica, Amst. 1704.

(37) p. 21.—"Lunam aquis carere et aëre: marium similitudinem in Luna nullam reperio. Nam regiones planas quæ montosis multo obscuriores sunt, quasque vulgo pro maribus haberi video et oceanorum nominibus insigniri, in his ipsis, longiore telescopio inspectis, cavitates exiguas inesse comperio rotundas, umbris intus cadentibus; quod maris superficiei convenire nequit: tum ipsi campi illi latiores non prorsus æquabilem superficiem præferunt, cum diligentius eas intuemur. Quodcirca maria esse non possunt, sed materia constare debent minus candicante, quam quæ est partibus asperioribus, in

quibus rursus quædam viridiori lumine cæteras præcellunt" (Hugeni Cosmotheoros, ed. alt. 1699, Lib. ii. p. 114). Huygens supposes, however, that there is much storm and rain in Jupiter, for "ventorum flatus ex illa nubium Jovialium mutabili facie cognoscitur" (Lib. i. p. 69). The reveries of Huygens respecting the inhabitants of the distant planets, which were not worthy of a severe mathematician, have been renewed unfortunately by Immanuel Kant in his excellent work, Allgemeine Naturgeschichte und Theorie des Himmels, 1755 (S. 173—192).

(38) p. 21.—Laplace, (des Oscillations de l'Atmosphère, du Flux solaire et lunaire,) in the Mécanique céleste, Livre iv.; and in the Exposition du Syst. du Monde, 1824, p. 291—296.

(39) p. 21.—"Adjicere jam licet de spiritu quodam subtilissimo corpora crassa pervadente et in iisdem latente, cujus vi et actionibus particulæ corporum ad *minimas distantias* se mutuo *attrahunt* et contiguæ factæ cohærent" (Newton, Principia Phil. nat. ed. Le Seur et Jacquier, 1760; Schol. gén. T. iii. p. 676). Compare also Newton, Opticks (ed. 1718), Query 31, p. 305, 353, 367, and 372. (Laplace, Syst. du Monde, p. 384; Kosmos, Bd. i. S. 56 and 74 (English edit. Vol. i. pp. 50 and x. Note 22).

(40) p. 22.—"Hactenus phænomena cœlorum et maris nostri per vim gravitatis exposui, sed causam gravitatis nondum assignavi. Oritur utique hæc vis a causa aliqua, quæ penetrat ad usque centra solis et planetarum, sine virtutis diminutione; quæque agit non pro quantitate superficierum particularum, in quas agit (ut solent causæ mechanicæ), sed pro quantitate materiæ solidæ.—Rationem harum gravitatis proprietatum ex phænomenis nondum potui deducere et hypotheses non fingo. Satis est quod gravitas revera existat et agat secundum leges a nobis expositas" (Newton, Principia Phil. Nat. p. 676). "To tell us that every species of things is endowed with an occult specifick quality, by which it acts and produces manifest effects, is to tell us nothing; but to derive two or three general principles of motion from phænomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered, and therefore I scruple not to propose the principles of motion, and leave their causes to be found out" (Newton, Opticks, p. 377). In an earlier place (Query 31, p. 351) it is said—"Bodies act one upon another by the attraction of gravity, magnetism, and electricity; and it is not improbable that there may be more attractive powers than these. How hese attractions may be performed, I do not here consider. What I call

attraction, may be performed by *impulse*, or by some other means unknown to me. I use that word here to signify any force by which bodies tend towards one another, whatsoever be the cause."

(41) p. 22.—"I suppose the rarer æther within bodies, and the denser without them." Operum Newtoni, Tomus iv. (ed. 1782, Sam. Horsley), p. 386; with application to the explanation of diffraction or bending of light discovered by Grimaldi. At the conclusion of Newton's letter to Robert Boyle, written in February 1678, p. 394, he says, "I shall set down one conjecture more which came into my mind: it is about the cause of gravity." Newton's correspondence with Oldenburg, in December 1675, also shows that he was not, at that period, disinclined to the hypothesis of an æther. According to it the impulse of material light would put the æther in vibration; the vibrations of the æther, which is akin to a nervous fluid, not by themselves producing light. See, respecting the controversy with Hook, Horsley, T. iv. p. 378—380.

(42) p. 22.—Brewster, Life of Sir Isaac Newton, p. 303—305.

(43) p. 23.—The precautionary explanation, "not to take gravity for an essential property of matter," given by Newton in the "Second Advertisement," contrasts with the forces of attraction and repulsion which he attributes to all molecules, in order to explain, in a manner accordant with the theory of emission, the phænomena of refraction and reflection of rays of light from mirror surfaces "before actual contact." (Newton, Opticks, Book ii. Prop. 8, p. 241; and Brewster's Life of Newton, p. 301.) According to Kant (Die metaphysischen Anfangsgründe der Naturwissenschaft, 1800, S. 28), the existence of matter, without these forces of attraction and repulsion, cannot be imagined. According to him, therefore, as according to the earlier Goodwin Knight (Phil. Trans. 1748, p. 264), all physical phænomena are to be traced back to the conflict of these two fundamental forces. In the atomic systems, which are diametrically opposed to Kant's dynamic views, and according to an assumption which was widely diffused, especially through the influence of Lavoisier, the attractive force is attributed to the ultimate particles or molecules of which all bodies consist, and the repulsive force to the atmospheres of caloric which surround the molecules. In this hypothesis, which regards the so-called caloric as matter in a constant state of expansion, there are assumed two different kinds of matter; *i. e.* two different elementary substances, as in the myth of two kinds of æther. (Newton, Opt. Query 28, p. 399.) One then asks, What is it which again expands this caloric matter? Considerations on the density of the molecules

in comparison with the density of their aggregates (the entire body), lead, in following atomic hypotheses, to the result, that the distance of the molecules from each other is much greater than their diameters.

(44) p. 24.—Kosmos, Bd. i. S. 98—102 (English edit. Vol. i. p. 85—89).

(45) p. 24.—Id. Bd. i. S. 39 and 50—56 (English. edit. Vol. i. p. 40 and 42—50).

(46) p. 24.—Wilhelm von Humboldt, Gesammelte Werke, Bd. i. S. 23.

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(47) p. 26.—Kosmos, Bd. i. S. 80 and 81 (English edition, Vol. i. p. 68 and 69).

(48) p. 27.—Id. S. 51 (English edition, p. 44).

(49) p. 27.—Halley, in the Phil. Trans. for 1717, Vol. xxx. p. 736.

(50) p. 28.—Pseudo-Plut. de plac. Philos. ii. 15—16; Stob. Eclog. phys. p. 582; Plato, in Tim. p. 40.

(51) p. 28.—Macrob. Somn. Scip. i. 9—10: "stellæ inerrantes," in Cicero de Nat. Deorum, iii. 20.

(52) p. 28.—The principal passage in which the technical expression, *ἐνδεδεμένα ἄστρα*, occurs, is Aristot. de Cœlo, ii. 8, p. 289, lin. 34; p. 290, lin. 19, Bekker. This alteration of the nomenclature had previously arrested my attention when engaged in examinations respecting Ptolemy's optics, and his experiments on the refraction of rays. Professor Franz, of whose philological learning I have often been glad to avail myself, remarks that Ptolemy (Syntax. vii. 1) also says of the fixed stars—*ἄστερ προσπεφυκότες*, as if fastened to the sky. Ptolemy blames the expression *σφαίρα ἀπλανής* (orbis inerrans), remarking that, "inasmuch as the stars always preserve their distances from each other, we may justly term them *ἀπλανεῖς*; but inasmuch as the whole sphere to which they are attached is in motion, the name *απλανὴς* seems but little suited thereto."

(53) p. 28.—Cicero de Nat. Deor. i. 13; Plin. ii. 6 and 24; Manilius, ii. 35.

(54) p. 30.—Kosmos, Bd. i. S. 91 (English edition, Vol. i. p. 78). Compare Encke's excellent considerations on the Arrangement of the Sidereal System, 1844, S. 7.

(55) p. 31.—Kosmos, Bd. i. S. 162 (English edition, Vol. i. p. 145).

(56) p. 31.—Aristot. de Cœlo, i. 7, p. 276, Bekker.

(57) p. 31.—Sir John Herschel, Outlines of Astronomy, 1849, § 803, p. 541.

(58) p. 32.—Bessel, in Schumacher's Jahrbuch für 1839, S. 50.

(59) p. 32.—Ehrenberg, in the Abhandl. der Berl. Akad. 1838, S. 59 ; in his "Infusionsthieren," S. 170.

(60) p. 33.—Aristotle, at that early period, argued against Leucippus and Democrites that there can be no unoccupied space—no void in the Universe (Phys. Auscult. iv. 6 to 10, p. 213—217, Bekker).

(61) p. 33.—"Âkâ'sa, according to Wilson's Sanscrit Dictionary, is 'the subtle and ethereal fluid supposed to fill and pervade the Universe, and to be the peculiar vehicle of light and sound.' The word âkâ'sa (shining) comes from the root kâ's, to shine, combined with the preposition â. The five elements collectively are called pantschatâ or pantschatra; and a dead man is, singularly enough, called one who has attained the five elements (prâpta-pantschatra), *i. e.* one who has been dissolved into the five elements. So in the text of the Amarakoscha, Amarasinha's Dictionary" (Bopp). Colebrook's excellent Memoir on the Sânkhya-Philosophy treats of the five elements (Transactions of the Asiatic Society, Vol. i. Lond. 1827, p. 31). Strabo (xv. § 59, p. 713, Cas.) notices, from Megasthenes, the fifth all-fashioning element of the Indians, without, however, naming it.

(62) p. 33.—Empedocles (v. 216) terms the æther *παμφανόων*, bright-beaming, therefore self-luminous.

(63) p. 33.—Plato, Cratyl. 410, B, where ἀειθεὴρ is found. Aristot. de Cœlo, i. 3, p. 270, Bekk., in opposition to Anaxagoras—*αιθέρα προσωνόμασαν τὸν ἀνωτάτω τόπον, ἀπὸ τοῦ θεῖν ἀει τόν ἀΐδιον χρόνον θεμενοι τῆν επωνυμιαν αὐτῶ. Αναξαγὸρας δὲ κατακέχρηται τῶ ὑνὸματι τούτω όυ καλῶς ὀνομάζει γαρ αιθέρα αντι πυρος.* In Aristot. Meteor. i. 3, p. 339, lin. 21—34, Bekk., it is said more in detail—"The so-called æther has an ancient appellation, which Anaxagoras appears to identify with fire; for the upper region, he says, is full of fire, and that upper region he looked upon as æther: and herein he was also right, for the bodies which move eternally in their courses appear to have been regarded by the ancients as having in their nature something divine, and therefore were called æther, as a substance to which there is nothing comparable on earth. Those, however, who regard surrounding space, and not merely the bodies which move in it, as fire, and all between the Earth and the stars as air, would surely give up their childish dream if they would accurately consider the results of the latest researches of mathematicians." (The same etymology of the word, from rapid revolution, is repeated by the author of the book De Mundo, cap. 2, p. 392, Bekk.) Professor Franz has justly remarked, "that the play upon words of bodies

engaged in an 'eternal course' (σῶμα ἀει θέον) and 'divine' (θεῖον), alluded to in the Meteorologica, is strikingly indicative of Greek fancy, and gives an additional evidence of the far from happy treatment of etymologies by the ancients." Professor Buschmann calls attention to a Sanscrit word, âschtra, for æther, atmosphere, which resembles much in appearance the Greek αιθηρ, and had been compared with it by Vans Kennedy, in his "Researches into the Origin and Affinity of the principal Languages of Asia and Europe," 1828, p. 279. There may be assigned to this word, also, a root (as, asch), to which the Indians attached the idea of "shining."

(64) p. 34.—Aristot. de Cœlo, iv. 1 and 3—4, p. 308 and 311—312, Bekk. If Aristotle refused to the æther the name of a fifth element—which, indeed, Ritter and Martin deny (vide Ritter, Geschichte der Philosophie, Th. iii. S. 259; and Martin, Etudes sur le Timée de Platon, T. ii. p. 150)—it was only because the æther, as a state of matter, appeared to him to want a counterpart (compare Biese, Philosophie des Aristoteles, Bd. ii. S. 66). With the Pythagoreans, æther as a fifth element was represented by the fifth of the regularly-formed bodies, the dodecahedron, composed of twelve pentagons (Martin, T. ii. p. 245—250).

(65) p. 34.—See on this subject the passages collected by Biese, Bd. ii. S. 93.

(66) p. 35.—Kosmos, Bd. i. S. 159 and 416, Note 88 (English edition, Vol. i. p. 143, Note 118).

(67) p. 35.—Compare the fine passage on the rays of the sun in Sir John Herschel's Outlines of Astronomy, p. 237 :—By the vivifying action of the sun's rays vegetables are enabled to draw support from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those *great deposits of dynamical efficiency which are laid up for human use in our coal strata*. By them the waters of the sea are made to circulate in vapour through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products, and originate a transfer of materials." . . . . .

(68) p. 35.—Phil. Trans. for 1795, Vol. lxxxv. p. 318; John Herschel, Outlines of Astronomy, p. 238; Kosmos, Bd. i. S. 195 and 436, Note 33 (English edition, Vol. i. p. 177 and Note 163).

(69) p. 36.—Bessel, in Schumacher's Astr. Nachr. Bd. xiii. 1836, No. 300, S. 201.

(70) p. 36.—Bessel, in the same, S. 186—192 and 229.

(71) p. 36.—Fourier, Théorie analytique de la Chaleur, 1822, p. ix. (Annales de Chimie et de Physique, T. iii. 1816, p. 350; T. iv. 1817, p. 128; T. vi. 1817, p. 259; T. xiii. 1820, p. 418.) Numerical estimations of the loss which the heat of the stars (chaleur stellaire) suffers in passing through space, by absorption in the ether, are attempted by Poisson, in his Théorie mathématique de la Chaleur, § 196, p. 436; § 200, p. 447; and § 228, p. 521.

(72) p. 36.—On the warming power of the stars, see Aristot. Meteor. i. 3, p. 340, lin. 28; and Seneca, on the height of the strata of the atmosphere which have the minimum of heat, in Nat. Quæst. ii. 10—"superiora enim aëris calorem vicinorum siderum sentiunt. . . . ."

(73) p. 36.—Plut. de plac. Philos. ii. 13.

(74) p. 37.—Arago sur la température du Pole et des espaces célestes, in the Annuaire du Bureau des Long. pour 1825, p. 189, and pour 1834, p. 192; Saigey, Physique du Globe, 1832, p. 60—78. From discussions on the refraction of rays, Svanberg finds, for the temperature of space, −50°.3 Cent., or −58°.5 F. (Berzelius, Jahresbericht für 1830, S. 54); Arago makes it, from polar observations, −56°.7 Cent. (−70° F.); Peclet, −60° Cent. (−76° F.); Saigey, by the diminution of heat in the atmosphere from 367 of my determinations in the Andes and in Mexico, −65° Cent. (−85° F.), and by thermometric observations on Mont Blanc and in Gay-Lussac's aerostatic voyage, −77° Cent. (−106°.6 F.); Sir John Herschel (Edinburgh Review, Vol. lxxxvii. 1848, p. 223) makes it −132° F. That Poisson, (the mean temperature of Melville Island, lat. 74° 47′, being already −18°.7 Cent. or—1°.7 F.), could deduce for the temperature of space, from purely theoretical grounds—[according to which space would be warmer than the extreme limit of the atmosphere (§ 227, p. 520)]—a temperature no lower than −13° or + 8°.6 F.,—while, on the other hand, Pouillet (Comptes rendus de l'Acad. des Sc. T. vii. 1838, p. 25-65) makes it −142° C. (223°.6 F),—must excite our astonishment, and diminish our confidence in the methods of inquiry hitherto pursued in these interesting speculations.

(75) p. 38.—Poisson, Théorie mathém. de la Chaleur, p. 438. According to him, the consolidation of the terrestrial strata began from the centre, and proceeded gradually from thence to the surface (§ 193, p. 429). Compare also Kosmos, Bd. i. S. 184 (English edition, Vol. i. p. 166).

(76) p. 38.—Kosmos, Bd. i. S. 86 and 149 (English edition, Vol. i. p. 74 and 133).

(77) p. 39.—"Were there no atmosphere, a thermometer, freely exposed (at sunset) to the heating influence of the earth's radiation, and the cooling

power of its own into space, would indicate a medium temperature between that of the celestial spaces (−132° F.) and that of the earth's surface below it (82° F. at the equator, −3°.5 F. in the Polar Sea). Under the equator, then, it would stand, on the average, at −25° F., and in the Polar Sea at −68° F. The presence of the atmosphere tends to prevent the thermometer so exposed from attaining these extreme low temperatures—first, by imparting heat by conduction; secondly, by impeding radiation outwards" (Sir John Herschel, in the Edinburgh Review, Vol. lxxxvii. 1848, p. 223). "Si la chaleur des espaces planétaires n'existoit point, notre atmosphère éprouverait un refroidissement, dont on ne peut fixer la limite. Probablement, la vie des plantes et des animaux seroit impossible à la surface du globe, ou réleguée dans une étroite zone de cette surface" (Saigey, Physique du Globe, p. 77).

(78) p. 39.—Traité de la Comète de 1743, avec une Addition sur la Force de la Lumière et sa Propagation dans l'Ether, et sur la Distance des Etoiles fixes, par Loys de Cheseaux (1744). On the transparency of space, see Olbers, in Bode's Jahrbuch für 1826, S. 110—121; Struve, Etudes d'Astr. stellaire, 1847, p. 83—93, and Note 95. Compare also Sir John Herschel, Outlines of Astr. §798; and Kosmos, Bd. i. S. 158 (English edit. vol. i. p. 142).

(79) p. 40.—Halley on the Infinity of the Sphere of Fixed Stars, in the Phil. Trans. Vol. xxxi. for the year 1720, p. 22—26.

(80) p. 40.—Kosmos, Bd. i. S. 92 (English Edition, Vol. i. p. 80).

(81) p. 40.—"Throughout by far the larger portion of the extent of the Milky Way in both hemispheres, the *general blackness* of the ground of the heavens on which its stars are projected," &c......."In those regions where that zone is clearly resolved into stars well separated, and seen projected *on a black ground*, and where we look out beyond them into space"......(Sir John Herschel, Outlines of Astronomy, p. 537 and 539).

(82) p. 40.—Kosmos, Bd. i. S. 89, 113, and 393, Note 23 (English edition, p. 77, 99, and Note 53); Laplace, Essai philosophique sur les Probabilités, 1825, p. 133; Arago, in the Annuaire du Bureau des Long. pour 1832, p. 188, pour 1836, p. 216; John Herschel, Outlines of Astronomy, § 577.

(83) p. 40.—The vibratory motion of the effluxes at the head of some comets—such as was observed in the comet of 1744, and by Bessel in Halley's comet between the 12th and 22d October, 1835 (Schumacher, Astron. Nachr. No. 300—302, S. 185—232)—"may, indeed, in particular individuals of this class of bodies, influence the translatory motion and the rotation, and even lead us to infer polar forces (S. 201 and 229) different from the ordinary attracting power of the Sun;" but the acceleration of the three and a half yearly period

of revolution of Encke's comet, which has already manifested itself with such great regularity for sixty-three years, cannot well be conceived to be dependent on a sum of accidental effluxes. Compare, respecting this cosmically important subject, Bessel, in Schumacher's Astr. Nachr. No. 289, S. 6, and No. 310, S. 345—350, with Encke's Memoir on the Hypothesis of a Resisting Medium, in Schum. No. 305, S. 265—274.

(84) p. 41.—Olbers, in Schum. Astr. Nachr. No. 268, S. 58.

(85) p. 41.—Outlines of Astronomy, § 556 and 597.

(86) p. 41.—"En assimilant la matière très rare qui remplit les espaces célestes quant à ses propriétés réfringentes aux gas terrestres, la densité de cette matière ne saurait dépasser une certaine limite dont les observations des étoiles changeantes, *p. e.* celles d'Algol ou de β de Persée, peuvent assigner la valeur (Arago, Annuaire pour 1842, p. 336—345).

(87) p. 41.—Wollaston, in the Phil. Trans. for 1822, p. 89; Sir John Herschel, Outl. of Astr. § 34 and 36.

(88) p. 42.—Newton, Princ. mathem. T. iii. (1760), p. 671:—"Vapores, qui ex sole et stellis fixis et *caudis cometarum* oriuntur, incidere *possunt* in atmosphæras planetarum.".........

(89) p. 42.—Kosmos, Bd. i. S. 129 and 141 (English edition, Vol. i. p. 114 and 126).

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(90) p. 43.—Kosmos, Bd. ii. S. 355—373 and 507—515 (English edition, Vol. ii. p. 314—330, Note 482—503).

(91) p. 43.—Delambre, Hist. de l'Astronomie moderne, T. ii. p. 255, 269, and 272. Morin says himself, in his Scientia Longitudinum, published in 1634—"Applicatio tubi optici ad alhidadam pro stellis fixis prompte et accurate mensurandis a me excogitata est." Picard used no telescope with his mural quadrant up to 1667; and Hevelius, when Halley visited him in 1679, at Dantzic, and admired the exactness of his measurements of altitude (Baily, Catal. of Stars, p. 38), observed through improved apertures for unassisted vision.

(92) p. 44.—The unfortunate Gascoigne, whose merits were long unacknowledged, met his death, when hardly 23 years of age, at the battle of Marston Moor, between Cromwell and the King's troops (see Derham, in the Phil. Trans. Vol. xxx. for 1717—1719, p. 603—610). To him belong inventions or adaptations which were long attributed to Picard and Anzout, and which gave to "Observing Astronomy,"—which has for its chief object

the determination of place in the heavens,—an extension and success never before attained.

([93]) p. 44.—Kosmos, Bd. ii. S. 209 (English edition, Vol. ii. p. 175).

([94]) p. 45.—The passage in which Strabo (Lib. iii. p. 138, Casaub.) seeks to refute the views of Posidonius, runs, according to the manuscript, as follows:—"The image of the sun, both at sunrise and sunset, is enlarged over the sea, because there the vapours ascend most abundantly from the humid element; for the eye, when it sees through vapours, as when it looks through tubes, receives the images refracted and enlarged: and the same thing happens when it sees the sun or moon set behind a thin dry cloud, in which case they also appear of a red colour." This passage has, quite lately, been supposed to be corrupt (Kramer, in Strabonis Geogr. 1844, Vol. i. p. 211); and it has been proposed to read in lieu of *δι αυλῶν*, *δι νάλων* (through glass globes) (Schneider, Eclog. phys. Vol. ii. p. 273). The magnifying power of hollow glass globes filled with water (Seneca, i. 6) was, indeed, known to the ancients, as well as the effects of burning glasses, or "burning crystals" (Aristoph. Nub. v. 765), and of Nero's emerald (Plin. xxxvii. 5); but certainly such globes could not serve for astronomical measuring instruments (compare Kosmos, Bd. ii. S. 464, Note 44; English edition, Vol. ii. Note 384). Altitudes of the Sun, taken through thin light clouds, or through volcanic vapours, show no trace of the influence of refraction (Humboldt, Recueil d'Observ. astr. Vol. i. p 123). Colonel Baeyer has been unable to find any angular alteration of the heliotrope light when streaks of mist were passing, or even with vapours purposely called forth,—thus confirming Arago's experiments. Peters, in Pulkova, in comparing groups of star-altitudes measured when the sky was clear with others observed through light clouds, finds no difference amounting to 0″.017 (see his Recherches sur la Parallaxe des Etoiles, 1848, p. 80 and 140—143; Struve, Études stellaires p. 98). On the employment of tubes in Arabian instruments, see Jourdain sur l'Observatoire de Meragah, p. 27; and A. Sédillot, Mém. sur les Instruments astronomiques des Arabes, 1841, p. 198. Arabian astronomers have also the merit of having first introduced large gnomons with small circular openings. In the colossal sextants of Abu Mohammed al-Chokandi, the limb, graduated to 5 minutes, received the image of the Sun itself. "A midi les rayons du Soleil passaient par une ouverture pratiquée dans la voûte de l'Observatoire qui couvrait l'instrument, suivaient le tuyau, et formaient sur la concavité du sextant une image circulaire, dont le centre donnait, sur l'arc gradué, le complément de la hauteur du Soleil. Cet instrument ne diffère de

notre Mural qu'en ce qu'il était garni d'un simple tuyau au lieu d'une lunette" Sédillot, p. 37, 202, and 205. Pierced Sight-vanes (Diopters, Pinnulæ,) were employed by the Greeks and Arabians for the determination of the diameter of the Moon in such manner, that the circular opening in the moveable object-diopter was larger than that of the eye-diopter, which did not move; and the former was moved until the disc of the Moon seen through the eye-aperture filled up the object-aperture (Delambre, Hist. de l'Astr. du moyen Age, p. 201; Sédillot, p. 198). The sight-vanes, with round or longitudinal openings of Archimedes, who made use of the direction of the shadows of two small cylinders attached to the same alidade, appear to be an arrangement first introduced by Hipparchus (Bailly, Hist. de l'Astr. mod. 2de édit. 1785, T. i. p. 480). Compare also Theon Alexandrin. Bas. 1538, p. 257 and 262; Les Hypotyp. de Proclus Diadochus, ed. Halma, 1820, p. 107 and 110; and Ptolem. Almag. ed. Halma, T. i. Par. 1813, p. lvii.

(95) p. 45.—According to Arago. See Moigno, Répert. d'Optique moderne, 1847, p. 153.

(96) p. 46.—Respecting the comportment of the dark streaks of the Sun's image in the Daguerreotype, see the Comptes rendus des Séances de l'Académie des Sciences, T. xiv. 1842, p. 902—904; and T. xvi. 1843, p. 402—407.

(97) p. 47.—Kosmos, Bd. ii. S. 370 (English edition, Vol. ii. p. 329).

(98) p. 47.—For the important distinction of proper and reflected light I may adduce, as an example, Arago's investigation of the light of comets. By the employment of chromatic polarisation, discovered by him in 1811, the production of the complementary colours, red and green, showed that the light of Halley's comet (1835) contained reflected solar light. I was myself present at his earlier attempts to compare, by means of the equal or unequal intensities of the images in the polariscope, the proper light of Capella with the light of the bright comet which emerged suddenly from amidst the rays of the Sun in the beginning of July 1819. Annuaire du Bureau des Long. pour 1836, p. 232; Kosmos, Bd. i. S. 111 and 392 (English edition, p. 97 and p. xix. Note 51); and Bessel, in Schumacher's Jahrbuch für 1837, S. 169.

(99) p. 47.—Lettre de M. Arago à M. Alexandre de Humboldt, 1840, p. 37:—"A l'aide d'un polariscope de mon invention, je reconnus (avant 1820), que la lumière de tous les corps terrestres incandescents, *solides* ou *liquides*, est de la lumière naturelle, tant qu'elle émane du corps sous des incidences perpendiculaires. La lumière, au contraire, qui sort de la surface incandescente sous un angle aigu, offre des marques manifestes de polarisation.

Je ne m'arrête pas à te rappeler içi comment je déduisis de ce fait la conséquence curieuse que la lumière ne s'engendre pas seulement à la surface des corps: qu'une portion nait *dans leur substance même,* cette substance fût-elle du platine. J'ai seulement besoin de dire qu'en répétant la même série d'épreuves, et avec les mêmes instruments, sur la lumière que lance une substance *gazeuse* enflammée, on ne lui trouve, sous quelque *inclinaison que ce soit,* aucun des caractères de la *lumière polarisée;* que la lumière des gaz, prise à la sortie de la surface enflammée, est de la lumière naturelle, ce qui n'empêche pas qu'elle ne se polarise ensuite complètement si on la soumet à des réflexions ou à des réfractions convenables. De là une méthode très simple pour découvrir à 40 millions de lieues de distance la nature du Soleil. La lumière provenant *du bord de cet astre,* la lumière emanée de la matière solaire *sous un angle aigu,* et nous arrivant sans avoir éprouvé en route des réflexions ou des réfractions sensibles, offre-t-elle des traces de polarisation, le Soleil est un corps *solide* ou *liquide.* S'il n'y a, au contraire, aucun indice de polarisation dans la lumière du bord, la *partie incandescente* du Soleil *est gazeuse.* C'est par cet enchaînement méthodique d'observations qu'on peut arriver à des notions exactes sur la constitution physique du Soleil." (On the envelopes of the Sun, see Arago, in the Annuaire pour 1846, p. 464.) I give all the detailed optical explanations which I borrow from the writings of my friend (whether manuscript or printed) in his own words, in order to avoid mistakes to which the fluctuations of scientific terminology might give rise in either retranslating into French or in translating into the several other languages in which Cosmos appears.

([100]) p. 47.—Sur l'effet d'une lame de tourmaline taillée parallèlement aux arrêtes du prisme servant, lorsqu'elle est convenablement située, à éliminer en totalité les rayons réfléchis par la surface de la mer et mêlés à la lumière provenant de l'écueil: vide Arago, Instructions de la Bonite, in the Annuaire pour 1836, p. 339—343.

([101]) p. 47.—De la possibilité de déterminer les pouvoirs réfringents des corps d'après leur composition chimique (applied to the proportions of oxygen and nitrogen in atmospheric air; to the quantity of hydrogen contained in ammonia and in water; to carbonic acid, alcohol, and the diamond), see Biot et Arago, Mémoire sur les Affinités des Corps pour la Lumière, March 1806; also, Mémoires mathém. et phys. de l'Institut, T. vii. p. 327—346; and my Mémoire sur les Réfractions astronomiques dans la Zone torride, in the Recueil d'Observ. astron. Vol. i. p. 115 and 122.

([102]) p. 47.—Expériences de M. Arago sur la puissance réfractive des

corps diaphanes (de l'air sec et de l'air humide) par le déplacement des franges, in Moigno, Répertoire d'Optique mod. 1847, p. 159—162.

([103]) p. 48.—In order to refute the statement of Aratus, that in the Pleiades there are only six stars visible, Hipparchus says, (Ad Arati Phæn. i. p. 190, in Uranologio Petavii) "A star has escaped Aratus; for if, in a clear and moonless light, one gazes steadfastly and keenly upon the constellation of the Pleiades, there appear in it seven stars: it seems, therefore, surprising that Attalus, in his description of the Pleiades, allows the oversight of Aratus to pass unnoticed, as if his statement had been correct." In the Catasterisms (xxiii.) attributed to Eratosthenes, Merope is termed "the invisible," πανaφανής. On a conjectured connection between the name of the veiled daughter of Atlas with geographical myths in the Meropis of Theopompus, as well as with the great Saturnian continent of Plutarch, and the Atlantis, see my Examen. crit. de l'Hist. de la Géographie, T. i. p. 170. Compare also Ideler, Untersuchungen über den Ursprung und die Bedeutung der Sternnamen, 1809, S. 145; and in reference to the determination of astronomical place, see Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. 1848, S. 36 und 166, as well as Baily, in the Mem. of the Astr. Soc. Vol. xiii. p. 33.

([104]) p. 48.—Ideler, Sternnamen, S. 19 und 25. "On observe," says Arago, "qu'une lumière forte fait disparaître une lumière faible placée dans le voisinage. Quelle peut en être la cause? Il est possible physiologiquement que l'ébranlement communiqué à la rétine par la lumière forte s'étend au delà des points que la lumière forte a frappés, et que cet ébranlement secondaire absorbe et neutralise en quelque sorte l'ébranlement provenant de la seconde et faible lumière. Mais sans entrer dans ces causes physiologiques, il y a une cause directe qu'on peut indiquer pour la disparition de la faible lumière: c'est que les rayons provenant de la grande n'ont pas seulement formé une image nette sur la rétine, mais se sont dispersés aussi sur toutes les parties de cet organe à cause des imperfections de transparence de la cornée. Les rayons du corps plus brillant, a, en traversant la cornée se comportent comme en traversant un corps légèrement dépoli. Une partie de ces rayons réfractés regulièrement forme l'image même de *a*, l'autre partie *dispersée* éclaire la totalité de la rétine. C'est donc sur ce fond lumineux que se projette l'image de l'objet voisin *b*. Cette dernière image doit donc ou disparaître ou être affaiblie. De jour deux causes contribuent à l'affaiblissement des étoiles: l'une de ces causes, c'est l'image distincte de cette portion de l'atmosphère, comprise dans la direction de l'étoile (de la portion aérienne placée entre l'œil et l'étoile), et sur laquelle l'image de l'étoile vient de se peindre; l'autre cause,

c'est la lumière diffuse provenant de la dispersion que les défauts de la cornée impriment aux rayons émanants de tous les points de l'atmosphère visible. *De nuit* les couches atmosphèriques interposées entre l'œil et l'étoile vers laquelle on vise, n'agissent pas; chaque étoile du firmament forme une image plus nette, mais une partie de leur lumière se trouve dispersée à cause du manque de diaphanité de la cornée. Le même raisonnement s'applique à une deuxième, troisième . . . . millième étoile. La rétine se trouve donc éclairée en totalité par une lumière diffuse proportionelle au nombre de ces étoiles et à leur éclat. On conçoit par là que cette somme de lumière diffuse affaiblisse ou fasse entièrement disparaître l'image de l'étoile vers laquelle on dirige la vue" (Arago, Manuscript, 1847).

(105) p. 50.—Arago, in the Annuaire for 1842, p. 284, and in the Comptes rendus, T. xv. 1842, p. 750; Schum. Astr. Nachr. No. 702. Dr. Galle writes to me—"With reference to your conjectures on the visibility of Jupiter's satellites, I have made some estimations of their magnitude, and, contrary to my own expectation, have found that they are not of the 5th, but only of the 7th, or at the utmost of the 6th magnitude. It was only the brightest of the satellites, the third, which showed itself at all equal to a neighbouring star of the 6th magnitude, which I could only recognise with the naked eye at some little distance from Jupiter: so that, making allowance for the brightness of Jupiter, this satellite might, perhaps, be estimated at from the 5th to the 6th magnitude if it stood alone. The fourth satellite was at its greatest elongation, but I could only estimate it at the 7th magnitude. The rays of Jupiter would not prevent this satellite from being visible if it were itself brighter. After comparisons of Aldebaran with the neighbouring clearly-recognisable double star, $\vartheta$ Tauri (with $5\frac{1}{2}$ minutes of distance), I estimate, for an ordinary eye, the radiation from Jupiter at from 5 to 6 minutes at least." These estimations agree with those of Arago; the latter even believes that the false rays may amount in some persons to double the quantity. The mean distances of the four satellites from the centre of the planet are, as is well known, 1′ 51″, 2′ 57″, 4′ 42″, and 8′ 16″. "Si nous supposons que l'image de Jupiter, dans certains yeux exceptionnels, s'épanouisse seulement par des rayons d'une ou deux minutes d'amplitude, il ne semblera pas impossible que les satellites soient de tems en tems aperçus sans avoir besoin de recourir à l'artifice de l'amplification. Pour vérifier cette conjecture, j'ai fait construire une petite lunette dans laquelle l'objectif et l'oculaire ont à peu près le même foyer, et qui dès lors *ne grossit point*. Cette lunette ne détruit pas entièrement les rayons divergents, mais elle en

reduit considérablement la longueur. Cela a suffi pour qu'un satellite convenablement écarté de la planète soit devenu visible. Le fait a été constaté par tous les jeunes astronomes de l'Observatoire" (Arago, in the Comptes rendus, T. xv. p. 751). I may instance, as a remarkable example of the keen sight and great sensibility of the retina in particular individuals who see Jupiter's satellites with the naked eye, a deceased master tailor of the name of Schön, in Breslau, respecting whom the learned and active Director of the Observatory of that place, Herr von Boguslawski, has given me interesting communications. "After being assured by repeated trials, since 1820, that in clear moonless nights Schön, with the naked eye, could assign correctly the position of Jupiter's satellites, even of more than one at a time, —on speaking to him of the rays and tails of light which seemed to prevent others from doing the same, he expressed his astonishment at it; and from the animated discussion which arose between him and the bystanders respecting the difficulty of seeing the satellites with the naked eye, I could not but infer that the planets and the fixed stars always appeared to him as luminous points, free from rays. He saw the third satellite best, and he could also see the first at its widest elongation; but he never saw the second or fourth. When the atmosphere was not quite favourable, the satellites appeared to him only as faint streaks of light. Small fixed stars, perhaps on account of their scintillating and less tranquil light, were never confounded by him with the satellites. Some years before his death, Schön complained to me that his eyes, as they grew older, could no longer reach Jupiter's satellites, and that now, even when the atmosphere was quite clear, their place was only marked to him by faint streaks." The above account agrees perfectly with what has long been known respecting the relative brightness of Jupiter's satellites; for, in individuals whose organs have so high a degree of perfection and sensibility, probably brightness and the quality of light are more influential than distance from the central planet. Schön never saw the second and fourth satellites: the second is the smallest of all; the fourth is, indeed, next to the third, the largest, and also the most distant, but periodically it is dark in colour, and at ordinary times it has the faintest light of any of the satellites. Of the third and first, which have been seen best and most often with the unassisted eye, the third is the largest of all, usually the brightest, and of a very decided yellow colour; but the first sometimes exceeds in the intensity of its bright yellow light the brightness of the third, which is much larger (Mädler, Astron. 1846, S. 231—234 und 439). How, by relations of refraction in the visual organ itself, distant luminous points may appear as

lines or streaks of light, has been shown by Sturm and Airy in the Comptes rendus, T. xx. p. 764—766.

([106]) p. 50.—"L'image *épanouie* d'une étoile de 7ème grandeur n'ébranle pas suffisamment la rétine : elle n'y fait pas naître une sensation appréciable de lumière. Si l'image *n'etait point épanouie* (par des rayons divergents), la sensation aurait plus de force et l'étoile se verrait. La première classe d'étoiles invisibles à l'œil nu ne serait plus alors la 7ème : pour la trouver, il faudrait peut-être descendre alors jusqu'à la 12ème. Considerons un groupe d'étoiles de 7ème grandeur tellement rapprochées les unes des autres que les intervalles échappent nécessairement à l'œil. *Si la vision avait de la netteté*,—si l'image de chaque étoile était tres petite et bien terminée, l'observateur apercevrait un champ de lumière dont chaque point aurait l'*éclat concentré* d'une étoile de 7ème grandeur. L'*éclat concentré* d'une étoile de 7ème grandeur suffit à la vision à l'œil nu. Le groupe serait donc visible à l'œil nu. Dilatons maintenant sur la rétine l'image de chaque étoile du groupe; remplacons chaque point de l'ancienne image générale par un petit cercle : ces cercles empiéteront les uns sur les autres, et les divers points de la rétine se trouveront éclairés par de la lumière venant simultanément de plusieurs étoiles. Pour peu qu'on y réfléchisse, il restera évident qu'excepté sur les bords de l'image générale l'aire lumineuse ainsi éclairée a précisément, à cause de la superposition des cercles, la même intensité que dans le cas où chaque étoile n'éclaire qu'un seul point au fond de l'œil ; mais si chacun de ces points reçoit une lumière égale en intensité à la lumière concentrée d'une étoile de 7e grandeur, il est clair que l'épanouissement des images individuelles des étoiles contigües ne doit pas empêcher la visibilité de l'ensemble. Les instruments télescopiques ont, quoiqu'à un beaucoup moindre degré, le défaut de donner aussi aux étoiles un *diamètre sensible et factice*. Avec ces instruments, comme à l'œil nu, on doit donc apercevoir des groupes, composés d'étoiles inférieures en intensité à celles que les mêmes lunettes ou télescopes feraient apercevoir isolément" (Arago, in the Annuaire du Bureau des Longitudes pour l'an 1842, p. 284).

([107]) p. 50.—Sir William Herschel, in the Phil. Trans. for 1803, Vol. xciii. p. 225 ; and for 1805, Vol. xcv. p. 184. Compare Arago, in the Annuaire pour 1842, p. 360—374.

([108]) p. 53.—Humboldt, Relation hist. du Voyage aux Régions équinox. T. i. p. 92—97 ; and Bouguer, Traité d'Optique, p. 360 and 365. Compare also Captain Beechey, in the Manual for Scientific Enquiry for the use of the Royal Navy, 1849, p. 71.

(109) p. 53.—The passage of Aristotle referred to by Buffon is in a book where one would least have looked for it—in the De generat. animal. v. 1, p. 780, Bekker. Closely translated, it is as follows:—"Keen sight means, on one side, the power of seeing far; and, on the other, an exact recognition of the differences between the things seen. Both are not the case at the same time in the same person; for a man holding his hand above his eyes, or looking through a tube, is not more or less able to judge of the difference between colours, but he will be able to see objects at a greater distance. Thus also it happens that those who are in vaults or cisterns sometimes see stars from them." Ορυγματα, and especially φρέατα, are subterranean cisterns or well-chambers, which, in Greece, are so constructed (as an eye-witness, Professor Franz, remarks) as to communicate with the air and light by a perpendicular shaft, widening below like the neck of a bottle. Pliny (Lib ii. cap. 14) says—"Altitudo cogit minores videri stellas; affixas cœlo Solis fulgor interdiu non cerni, quum aeque ac noctu luceant: idque manifestum fiat *defectu Solis et prœaltis puteis.*" Cleomedes (Cycl. Theor. p. 83, Bake) does not speak of stars being seen in the day-time, but he states "that the Sun, seen from deep cisterns, appears larger by reason of the darkness and the damp air."

(110) p. 54.—"We have ourselves heard it stated by a celebrated optician, that the earliest circumstance which drew his attention to astronomy, was the regular appearance, at a certain hour, for several successive days, of a considerable star through the shaft of a chimney" (John Herschel, Outlines of Astronomy, § 61). The chimney-sweepers from whom I have inquired, say pretty uniformly, "that they never see stars in the day-time; but that at night the sky seen through tall chimneys looks quite near, and the stars seem larger." I forbear from any consideration of the connection between these two illusions.

(111) p. 54.—Saussure, Voyage dans les Alpes (Neuchatel, 1779, 4to.) T. iv. § 2007, p. 199.

(112) p. 55.—Humboldt, Essai sur la Géographie des Plantes, p. 103. Compare also my Voy. aux Régions équinox. T. i. p. 143 and 248.

(113) p. 56.—Humboldt, in Baron Zach's Monatlicher Correspondenz zur Erd- und Himmels-kunde, Bd. i. 1800, S. 396; and in Voy. aux Régions équin. T. i. p. 125. "On croyoit voir de petites fusées lancées dans l'air. Des points lumineux, élevés de 7 à 8 degrés, paroissoient d'abord se mouvoir dans le sens vertical, mais puis se convertir en une véritable oscillation horizontale. Ces points lumineux étoient des images de plusieurs étoiles agrandies (en

apparence) par les vapeurs et revenant au même point d'où elles étoient parties."

([114]) p. 56.—Prinz Adalbert von Preussen, Aus meinem Tagebuche, 1847, S. 213. May the phænomenon described by me be connected with that which Carlini observed at the passage of the Pole star, and its oscillations of 10—12 seconds, with the strongly-magnifying meridian telescope at Milan? (See Zach, Correspondance astronomique et géogr. Vol. ii. 1819, p. 84). Brandes (Gehler's umgearb. phys. Wörterb. Bd. iv. S. 549) is disposed to refer them to mirage. The star-like light of the heliotrope has also been seen by an excellent and practised observer, Colonel Baeyer, often uctuating horizontally to and fro.

([115]) p. 60.—The distinguished merit as an artist of Constantine Huygens, who was secretary to King William III., has only recently been placed in its true light by Uptenbrock, in the Oratio de fratribus Christiano atque Constantino Hugenio, artis dioptricæ cultoribus, 1838; and by the learned Director of the Leyden Observatory, Professor Kaiser, in Schumacher's Astr. Nachr. No. 592, S. 246.

([116]) p. 60.—Arago, in the Annuaire for 1844, p. 381.

([117]) p. 60.—"Nous avons placé ces grands verres," says Dominique Cassini, "tantôt sur un grand mât, tantôt sur la *tour de bois venue de Marly;* enfin nous les avons mis dans un tuyau monté sur un support en forme d'échelle à trois faces, ce qui a eu (dans la découverte des satellites de Saturne) le succès que nous en avions espéré." (Delambre, Hist. de l'Astr. moderne, T. ii. p. 785.) These excessive lengths of optical instruments remind us of the Arabian quadrants of about 190 feet radius, in the divided limb of which the image of the sun fell, as in a gnomon, through a small round aperture. There was such a quadrant at Samarcand, probably imitated from an earlier-constructed sextant of Al-Chokandi, about 60 feet high. Compare Sédillot, Prolégomènes des Tables d'Oloug Beigh, 1847, p. lvii. and cxxix.

([118]) p. 60.—Delambre, Hist. de l'Astr. mod. T. ii. p. 594. The Capuchin Monk, Schyrle von Rheita, a mystic, but highly experienced in optical matters, had previously spoken, in his Oculus Enoch et Eliæ (Antv. 1645), of the expected possibility of soon obtaining magnifying powers of 4000 for telescopes, in order to give accurate maps of the Moon. Compare Kosmos, Bd. ii. S. 511, Note 48 (English edition, p. cxvi. Note 488).

([119]) p. 61.—Edinb. Encyclopædia, Vol. xx. p. 479.

([120]) p. 61.—Struve, Etudes d'Astr. stellaire, 1847, Note 59, p. 24. I have preserved in the text the denominations of Herschel's reflectors of 40,

20, and 7 English feet (though I use French measures everywhere else), not only as more convenient, but also because the great labours of the father and son in England and at Feldhausen, at the Cape of Good Hope, have given to the names of these instruments an historical interest. [The French measures are converted into English throughout this translation; retaining, however, the original measures in addition wherever precision seems important, and there could be room for doubt. But in the cases of the focal length by which the telescopes severally referred to in pp. 59 and 60 of the text are designated, the lengths specified by M. de Humboldt are left unchanged, for reasons similar to those adduced by himself in the case of the Herschelian telescopes.—Ed.]

(121) p. 62.—Schumacher's Astr. Nachr., No. 371 and 611. Cauchoix and Lerebours have also sent out object-glasses of more than 12½ (12·61 Eng.) Paris inches, and 23½ (24½ Eng.) feet focal length.

(122) p. 63.—Struve, Stellarum duplicium et multiplicium Mensuræ micrometricæ, p. 2—41.

(123) p. 64.—Mr. Airy has recently given a comparative description of the methods of construction of these telescopes,—the casting of the mirrors and mixing of the metal, the polishing and the mounting (Abstr. of the Astr. Soc. Vol. ix. No. 5, March 1849). Of the effect of the 6-foot metallic mirror of the Earl of Rosse, it is there said (p. 120):—"The Astronomer-Royal (Mr. Airy) alluded to the impression made by the enormous light of the telescope: partly by the modifications produced in the appearances of nebulæ already figured, partly by the great number of stars seen even at a distance from the Milky Way, and partly from the prodigious brilliancy of *Saturn*. The account given by another astronomer of the appearance of *Jupiter* was, that it resembled a coach-lamp in the telescope; and this well expresses the blaze of light which is seen in the instrument." Compare also Sir John Herschel, Outlines of Astronomy, § 870:—"The sublimity of the spectacle afforded by the magnificent reflecting telescope constructed by Lord Rosse of some of the larger globular and other clusters, is declared by all who have witnessed it to be such as no words can express. This telescope has resolved or rendered resolvable multitudes of nebulæ which had resisted all inferior powers."

(124) p. 64.—Delambre, Hist. de l'Astr. moderne, T. ii. p. 255.

(125) p. 65.—Struve, Mens. microm. p. xliv.

(126) p. 65.—Schumacher's Jahrbuch für 1839, S. 100.

(127) p. 65.—"*La lumière atmosphérique diffuse* ne peut s'expliquer par le reflet des rayons solaires sur la surface de séparation des couches de différentes

densités dont on suppose l'atmosphère composée. En effet supposons le Soleil placé à l'horizon, les surfaces de séparation dans la direction du zénith seraient horizontales; par conséquent la réflexion serait horizontale aussi, et nous ne verrions aucune lumière au zénith. Dans la supposition des couches, aucun rayon ne nous arriverait par voie d'une première réflexion. Ce ne seraient que les réflexions multiples qui pourraient agir. Donc pour expliquer la *lumière diffuse*, il faut se figurer l'atmosphère composée de molécules (sphériques, par example) dont chacune donne une image du soleil à peu près comme les boules de verres que nous plaçons dans nos jardins. L'air pur est bleu, parce que d'après Newton les molécules de l'air ont l'*épaisseur* qui convient à a réflexion des rayons bleus. Il est donc naturel que les petites images du soleil que de tous côtés réfléchissent les molécules sphériques de l'air, et qui sont la lumière diffuse, aient une teinte bleue; mais ce bleu n'est pas du bleu pur, c'est un blanc dans lequel le bleu prédomine. Lorsque le ciel n'est pas dans toute sa pureté, et que l'air est mêlé de vapeurs visibles, la lumière diffuse reçoit beaucoup de blanc. Comme la lune est jaune, le bleu de l'air pendant la nuit est un peu verdâtre, c'est-à-dire mélangé de bleu et de jaune." (Arago, Manuscript, 1847.)

([123]) p. 65.—D'un des Effets des Lunettes sur la visibilité des étoiles (Lettre de M. Arago à M. de Humboldt, en Déc. 1847) :—" L'œil n'est doué que d'une sensibilité circonscrite, bornée. Quand la lumière qui frappe la rétine n'a pas assez d'intensité, l'œil ne sent rien. C'est par un manque d'intensité que beaucoup d'*étoiles*, même dans les nuits les plus profondes, échappent à nos observations. Les lunettes ont pour effet, *quant aux étoiles* d'augmenter l'intensité de l'image. Le faisceau cylindrique de rayons parallèles venant d'une étoile, qui s'appuie sur la surface de la lentille objective, et qui a cette surface circulaire pour base, se trouve considérablement resserré à la sortie de la lentille oculaire. Le diamètre du premier cylindre est au diamétre du second comme la distance focale de l'objectif est à la distance focale de l'oculaire, ou bien comme le diamètre de l'objectif est au diamètre *de la portion d'oculaire* qu'occupe le faisceau émergent. Les intensités de lumière dans les deux cylindres en question (dans les deux cylindres incident et émergent) doivent être entr'elles comme les étendues superficielles des bases. Ainsi la lumière émergente sera plus condensée, *plus intense* que la lumière naturelle tombant sur l'objectif, dans le rapport de la surface de cet objectif â la surface circulaire de la base du faisceau émergent. Le faisceau *émergènt, quand la lunette grossit*, étant plus étroit que le faisceau cylindrique qui tombe sur l'objectif, il est évident que la pupille, quelle que soit son ouverture,

recueillera plus de rayons par l'intermédiaire de la lunette que sans elle. La lunette augmentera donc toujours l'intensité de la lumière *des étoiles.*

"Le cas *le plus favorable,* quant à l'effet des lunettes, est évidemment celui où l'œil reçoit la totalité du faisceau émergent, le cas où ce faisceau a moins de diamètre que la pupille. Alors *toute la lumière* que l'objectif embrasse, concourt, par l'entremise du télescope, à la formation de l'image. A l'œil nu, au contraire, *une portion* seule de cette même lumière est mise à profit : c'est la petite portion que la surface de la pupille découpe dans le faisceau incident naturel. L'intensité de l'image télescopique d'une *étoile* est donc à l'intensité de l'image à l'œil nu, *comme la surface de l'objectif est à celle de la pupille.*

"Ce qui précède est relatif à la visibilité d'un seul point—d'une seule étoile. Venons à l'observation d'un objet ayant des dimensions angulaires sensibles,—à l'observation d'une *planète.* Dans les cas les plus favorables, c'est-à-dire lorsque la pupille reçoit la totalité du pinceau émergent, l'intensité de l'image *de chaque point* de la planète se calculera par la proportion que nous venons de donner. La quantité *totale de lumière* concourant à former *l'ensemble* de l'image à l'œil nu, sera donc aussi à la *quantité totale de lumière* qui forme l'image de la planète, à l'aide d'une lunette, comme la surface de la pupille est à la surface de l'objectif. Les intensités comparatives, non plus de points isolés, mais des deux images d'une planète, qui se forment sur la rétine à l'œil nu, et par l'intermédiare d'une lunette, doivent évidemment *diminuer* proportionnellement aux *étendues superficielles* de ces deux images. Les dimensions *linéaires* des deux images sont entr'elles comme le diamètre de l'objectif est au diamètre du faisceau émergent. Le nombre de fois que la *surface* de l'image amplifiée surpasse la *surface* de l'image à l'œil nu, s'obtiendra donc en divisant le carré du *diamètre* de *l'objectif* par le carré du *diamètre du faisceau émergent,* ou bien la *surface de l'objectif par la surface de la base circulaire du faisceau émergent.*

"Nous avons déjà obtenu le rapport des *quantités totales de lumière* qui engendrent les deux images *d'une planète,* en divisant la surface de l'objectif *par la surface de la pupille.* Ce nombre est *plus petit* que le quotient auquel on arrive en divisant la *surface de l'objectif* par la *surface du faisceau émergent.* Il en résulte, quant aux planètes, qu'une lunette fait moins gagner en intensité de lumière qu'elle ne fait perdre en agrandissant *la surface* des images sur la rétine : l'intensité de ces images doit donc aller continuellement en s'affaiblissant à mesure que le pouvoir amplificatif de la lunette ou du télescope s'accroît.

"L'atmosphère peut être considérée comme une planète à dimensions indéfinies. La portion qu'on en verra dans une lunette subira donc aussi la *loi* d'affaiblissement que nous venons d'indiquer. Le *rapport* entre l'intensité de la lumière d'une *planète* et le champ de lumière atmosphérique à travers lequel on la verra, sera le même à l'œil nu et dans les lunettes de tous les grossissements, de toutes les dimensions. Les lunettes, *sous le rapport de l'intensité*, ne favorisent donc pas la visibilité *des planètes*.

"Il n'en est point ainsi des *étoiles*. L'intensité de l'image d'une étoile est plus forte avec une lunette qu'à l'œil nu; au contraire, le champ de la vision, uniformément éclairé dans les deux cas par la lumière atmosphérique, est plus clair à l'œil nu que dans la lunette. Il y a donc deux raisons, sans sortir des considérations d'intensité, pour que dans une lunette l'image de l'étoile prédomine sur celle de l'atmosphère notablement plus qu'à l'œil nu.

"Cette prédominence doit aller graduellement en augmentant avec le grossissement. En effet, abstraction faite de certaine augmentation du diamètre de l'étoile, conséquence de divers effets de *diffraction* ou *d'interférences;* abstraction faite aussi d'une plus forte réflexion que la lumière subit sur les surfaces plus obliques des oculaires de très courts foyers, *l'intensité de la lumière de l'étoile est constante* tant que l'ouverture de l'objectif ne varie pas. Comme on l'a vu, la *clarté du champ* de la lunette, au contraire, *diminue sans cesse* à mesure que le pouvoir amplificatif s'accroît. Donc, toutes autres circonstances restant égales, une étoile sera d'autant plus visible—sa prédominence sur la lumière du champ du télescope sera d'autant plus tranchée—qu'on fera usage d'un grossissement plus fort." (Arago, Manuscript, 1847.) I add from the Annuaire du Bureau des Long. pour 1846 (Notices scient. par M. Arago), p. 381:—"L'expérience a montré que pour le commun des hommes, deux espaces éclairés et contigus ne se distinguent pas l'un de l'autre; à moins que leurs intensités comparatives ne présentent, au minimum, une différence de $\frac{1}{60}$. Quand une lunette est tournée vers le firmament, son champ semble uniformément éclairé: c'est qu'alors il existe, dans un plan passant par le foyer et perpendiculaire à l'axe de l'objectif, une *image indéfinie* de la région atmosphérique vers laquelle la lunette est dirigée. Supposons qu'un astre, c'est-à-dire un objet situé bien au delà de l'atmosphère, se trouve dans la direction de la lunette: son image ne sera visible qu'autant qu'elle augmentera de $\frac{1}{60}$, au moins, l'intensité de la portion de l'image focale *indéfinie* de l'atmosphère sur laquelle sa propre image *limitée* ira se placer. Sans cela, le champ visuel continuera à *paraître* partout de la même intensité."

(129) p. 67.—The earliest publication of Arago's explanation of the phæno-

menon of scintillation was in the Appendix to the 4th book of my Voyage aux Régions équinoxiales, T. i. p. 623. I have great pleasure in being enabled to enrich the section upon natural and telescopic vision with the following extracts from the MSS. of my friend, which, for reasons already given, I print in the original:—Des Causes de la Scintillation des Etoiles: "Ce qu'il y a de plus remarquable dans le phénomène de la scintillation, c'est le changement de couleur. Ce changement est beaucoup plus fréquent que l'observation ordinaire ne l'indique. En effet, en agitant la lunette on transforme l'image dans une ligne ou un cercle, et tous les points de cette ligne ou de ce cercle paraissent de couleurs différentes. C'est la résultante de la superposition de toutes ces images que l'on voit lorsqu'on laisse la lunette immobile. Les rayons qui se réunissent au foyer d'une lentille, vibrent d'accord ou en désaccord, s'ajoutent ou se détruisent, suivant que les couches qu'ils ont traversé, ont telle ou telle réfringence. L'ensemble des rayons rouges peut se détruire *seul* si ceux de droite et de gauche, et ceux de haut et de bas, ont traversé des milieux inégalement réfringents. Nous avons dit *seul*, parce que la différence de réfringence qui correspond à la destruction du rayon rouge n'est pas la même que celle qui amène la destruction du rayon vert, et réciproquement. Maintenant si des rayons rouges sont détruits, ce qui reste sera le blanc moins le rouge, c'est-à-dire du vert; si le vert, au contraire, est détruit par *interference*, l'image sera du blanc moins le vert, c'est-à-dire du rouge. Pour expliquer pourquoi les planètes à grand diamètre ne scintillent pas, ou très peu, il faut se rappeller que le disque peut être considéré comme une aggrégation d'étoiles ou de petits points qui scintillent isolément; mais les images de différentes couleurs que chacun de ces points pris isolément donnerait, empiétant les unes sur les autres, formeraient du blanc. Lorsqu'on place un diaphragme ou un bouchon percé d'un trou sur l'objectif d'une lunette, les étoiles acquièrent un disque entouré d'une série d'anneaux lumineux. Si l'on enfonce l'oculaire, le disque de l'étoile augmente de diamètre, et il se produit dans son centre un trou obscur; si l'on enfonce davantage, un point lumineux se substitue au point noir: un nouvel enfoncement donne naissance à un centre noir, etc. Prenons la lunette lorsque le centre de l'image est noir, et visons à une étoile qui ne scintille pas: le centre restera noir, comme il l'était auparavant. Si, au contraire, on dirige la lunette à une étoile qui scintille, on verra le centre de l'image lumineux et obscur par intermittence. Dans la position où le centre de l'image est occupé par un point lumineux, on verra ce point disparaître et renaître successivement. Cette disparition ou réapparition du point central est la preuve directe de l'*interférence* variable des rayons.

Pour bien concevoir l'absence de lumière au centre de ces images dilatées, il faut se rappeler que les rayons régulièrement réfractés par l'objectif ne se réunissent et ne peuvent par conséquent *interférer* qu'au foyer: par conséquent les images dilatées que ces rayons peuvent produire resteraient toujours pleines (sans trou). Si dans une certaine position de l'oculaire un trou se présente au centre de l'image, c'ést que les rayons régulièrement réfractés *interfèrent* avec des rayons *diffractés* sur les bords du diaphragme circulaire. Le phénomène n'est pas constant, parce que les rayons qui interfèrent dans un certain moment n'interfèrent pas un instant après, lorsqu'ils ont traversé des couches atmosphériques dont le pouvoir refringent a varié. On trouve dans cette expérience la preuve manifeste du rôle que joue dans le phénomène de la scintillation l'inégale réfrangibilité des couches atmosphériques traversées par les rayons dont le faisceau est très étroit.

"Il résulte de ces considérations que l'explication des scintillations ne peut être rattachée qu'au phénomènes des *interférences lumineuses.* Les rayons des étoiles, après avoir traversé une atmosphère où il existe des couches inégalement chaudes, inégalement denses, inégalement humides, vont se réunir au foyer d'une lentille, pour y former des images d'intensité et de couleurs perpétuellement changeantes, c'est-à-dire des images telles que la scintillation les présente. Il y a aussi scintillation hors du foyer des lunettes. Les explications proposées par Galilei, Scaliger, Kepler, Descartes, Hooke, Huygens, Newton et John Michell, que j'ai examinées dans un mémoire présenté à l'Institut en 1840 (Comptes rendus, T. x. p 83), sont inadmissibles. Thomas Young, auquel nous devons les premières lois des interférences, a cru inexplicable le phénomène de la scintillation. La fausseté de l'ancienne explication par des vapeurs qui voltigent et déplacent, est déjà prouvée par la circonstance que nous voyons la scintillation des yeux, ce qui supposeraït un déplacement d'une minute. Les ondulations du bord du Soleil sont de 4″ à 5″, et peut-être des pièces qui *manquent,* donc encore effet de l'interférence des rayons." (Extracted from MSS. of Arago, 1847.)

(130) p. 68.—Arago, in the Annuaire for 1831, p. 168.

(131) p. 69.—Aristot. de Cœlo, ii. 8, p. 290, Bekker.

(132) p. 69.—Kosmos, Bd. ii. S. 363 (English edition, p. 322).

(133) p. 69.—Causæ Scintillationis, in Kepler de Stella nova in pede Serpentarii, 1606, cap. 18, p. 92—97.

(134) p. 70.—Lettre de M. Garcin, Dr. en Méd., à M. de Réaumur, in the Hist. de l'Académie Royale des Sciences, Année 1743, p. 28—32.

(135) p. 71.—See Voyage aux Régions équin. T. i. p. 511 and 512, T. ii.

p. 202—208; also my Ansichten der Natur, 3te Ausg. Bd. i. S. 29 and 225. "En Arabie," says Garcin, "de même qu'à Bender-Abassi, port fameux du Golfe Persique, l'air est parfaitement serein presque toute l'année. Le printemps, l'éte et l'automme se passent, sans qu'on y voie la moindre rosée. Dans ces mêmes temps tout le monde couche dehors sur le haut des maisons. Quand on est ainsi couché, il n'est pas possible d'exprimer le plaisir qu'on prend à contempler la beauté du ciel, l'éclat des étoiles. C'est une lumière pure, ferme et éclatante, sans étincillement. Ce n'est qu'au milieu de l'hiver que la scintillation, quoique très-foible, s'y fait apercevoir." (Garcin, in Hist. de l'Acad. des Sciences, 1743, p. 30.)

([136]) p. 72.—Speaking of the illusions occasioned by the different velocities of sight and sound, Bacon says—"Atque hoc cum similibus nobis quandoque dubitationem peperit plane monstrosam; videlicet, utrum cœli sereni et stellati facies ad idem tempus cernatur, quando vere existit, an potius aliquanto post; et utrum non sit (quatenus ad visum cœlestium) non minus tempus verum et tempus visum, quam locus verus et locus visus, qui notatur ab astronomis in parallaxibus. Adeo incredibile nobis videbatur, species sive radios corporum cœlestium, per tam immensa spatia milliarium, subito deferri posse ad visum; sed potius debere eas in tempore aliquo notabili delabi. Verum illa dubitatio (quoad majus aliquod intervallum temporis inter tempus verum et visum) postea plane evanuit, reputantibus nobis." (The Works of Francis Bacon, Vol. i. Lond. 1740—(Novum Organum), p. 371.) He then, quite in the manner of the Ancients, recalls a true view just expressed. Compare Somerville, The Connexion of the Physical Sciences, p. 36; and Kosmos, Bd. i. S. 161 (English edition, Vol. i. p. 144—145).

([137]) p. 72.—See Arago's development of his method, in the Annuaire du Bureau des Longitudes pour 1842, p. 337—343: "L'observation attentive des phases d'Algol à six mois d'intervalle servira à déterminer directement la vitesse de la lumière de cette étoile. Près du maximum et du minimum le changement d'intensité s'opère lentement; il est, au contraire, rapide à certaines époques intermédiaires entre celles qui correspondent aux deux états extrêmes, quand Algol, soit en diminuant, soit en augmentant d'éclat, passe par la troisième grandeur."

([138]) p. 72.—Newton, Opticks, 2d edit. (Lond. 1718), p. 325: "Light moves from the Sun to us in seven or eight minutes of time." Newton compares the velocity of sound ("1140 feet in one second") with that of light. Reckoning for the latter, according to the occultations of Jupiter's

satellites (Newton died about half a year before Bradley's discovery of aberration), 7′ 30″ from the Sun to the Earth, and assuming a distance of 70 millions of English (statute) miles,—light traverses, in every second of time, $155555\frac{5}{9}$ English miles, the reduction of which to geographical miles would vary according to the assumption of the figure of the Earth. According to Encke's exact assumptions in the Jahrbuch for 1852 (taking, with Dove, 1 English mile = 5280 English feet = 4954·206 Paris feet), there are 691637 English statute miles to an equatorial degree. Newton's result would thus be 33736 German geographical miles 15 to a degree, (or 134944 English geographical miles 60 to a degree, which are generally used throughout this translation under the name of "geographical miles"). But Newton took the Sun's parallax at 12″: if it is 8″·57116, as given by Encke's calculation of the transit of Venus, the distance is greater, and we should have for the velocity of light (taking $7\frac{1}{2}$′ from the Sun) 47232 German, or 188928 English geographical miles for a second of time,—too much, therefore, instead of, as before, too little. It is certainly very remarkable, though it was not noticed by Delambre (Hist. de l'Astronomie moderne, T. ii. p. 653), that whereas, from Römer's discovery in 1675 to the beginning of the 18th century, the times assigned for the passage of light over half the major axis of the Earth's orbit fluctuated between 11′ and 14′ 10″,—being always much too high,—Newton, supported perhaps by more recent English observations of the first satellite, came within about 47″ of the truth (or, at least, of the now accepted result of Struve). The oldest memoir in which Römer, who was Picard's pupil, presented his discovery to the Academy, bears date Nov. 22, 1675. He found, by forty emersions and immersions of Jupiter's satellites, "un retardement de lumière de 22 minutes par l'intervalle qui est le double de celui qu'il y a d'ici au Soleil" (Mémoires de l'Acad. de 1666—1699, T. x. 1730, p. 400). Cassini did not contest the fact of the retardation, but he contested the assigned amount of time, because (he very erroneously supposed) different satellites gave different results. Du Hamel, the Secretary of the Paris Academy (Regiæ Scientiarum Academiæ Historia, 1698, p. 145), seventeen years after Römer had left Paris, but still referring to him, gives from 10′ to 11′; but we know, by Peter Horrebow (Basis Astronomiæ, sive Triduum Roemerianum, 1735, p. 122—129), that in 1704—six years, therefore, before his death—when about to publish his own work on the velocity of light, Römer kept steadily to the result of 11′: so, also, did Huygens (Tract. de Lumine, cap. 1, p. 7). Cassini proceeded quite differently: he found for the first satellite 7′ 5″, for the second 14′ 12″; and he

lays down, as the basis of his tables of Jupiter, 14′ 10″ "pro peregrando diametri semissi." The error was therefore on the increase. (Compare Horrebow, Triduum, p. 129; Cassini, Hypothèses et Satellites de Jupiter, in the Mém. de l'Acad. 1666—1699, T. viii. p. 435 and 475; Delambre, Hist. de l'Astr. moderne, T. ii. p. 751 and 782; Du Hamel, Physica, p. 435.)

([139]) p. 72.—Delambre, Hist. de l'Astr. mod. T. ii. p. 653.

([140]) p. 73.—Reduction of Bradley's Observations at Kew and Wansted, 1836, p. 22; Schumacher's Astr. Nachr. Bd. xiii. 1836, No. 309. (Compare Miscellaneous Works and Correspondence of the Rev. James Bradley, by Professor Rigaud, Oxford, 1832.) On the attempts hitherto made to explain the aberration of light on the undulatory theory, see Doppler, in the Abhandl. der kön. böhmischen Gesellschaft der Wiss. 5te Folge, Bd. iii. S. 745—765. It is a circumstance deserving of particular attention in the history of great astronomical discoveries, that more than half a century before Bradley's actual discovery and explanation of the cause of aberration (probably from 1667), Picard remarked a periodical movement of the Pole-star of about 20″, which "can neither be the effect of parallax or of refraction, and is very regular in the opposite seasons of the year" (Delambre, Hist. de l'Astr. moderne, T. ii. p. 616). Picard was on the path which might have led to the discovery of the velocity of direct light, half a century before his disciple Römer made known the velocity of reflected light.

([141]) p. 73.—Schum. Astr. Nachr. Bd. xxi. 1844, No. 484; Struve, Etudes d'Astr. stellaire, p. 103 and 107 (compare Kosmos, Bd. i. S. 160; English edition, p. 144). In the Annuaire pour 1842, p. 287, the velocity of light is given at 308000 kilometres, or 77000 lieues (each 4000 metres), in a second: this result comes nearest to the present one of Struve. It gives 41507 German, or 166028 English geographical miles, in a second; that of the Pulkova Observatory being 41549 German, or 166196 English geographical miles in a second. On the difference between the aberration of the Pole-star and that of its companion, and on Struve's own recently-conceived doubts, see Mädler, Astronomie, 1849, S. 393. A still larger result for the passage of light from the Sun to the Earth is given by William Richardson, viz. 8′ 19″·28, to which belongs a velocity of 165688 geographical miles (Mem. of the Astron. Soc. Vol. iv. Pt. 1, p. 68).

([142]) p. 74.—Fizeau gives his result in leagues, 25 to an equatorial degree, 70000 such leagues in a second (168000 English geographical miles). On earlier experiments of Fizeau, see Comptes rendus, T. xxix. p. 92. In Moigno, Répert. d'Optique moderne, P. iii. p. 1162, the result is given at

70843 (25 = 1°): therefore 42506 German, or 170024 English geographical miles, which comes nearest to Bradley's result, according to Busch.

(143) p. 74.—D'après la théorie mathématique dans le système des ondes, les rayons de différentes couleurs, les rayons dont les ondulations sont inégales, doivent néanmoins se propager dans l'Ether avec la même vitesse. Il n'y a pas de différence à cet égard entre la propagation des ondes sonores, lesquelles se propagent dans l'air avec la même rapidité. Cette égalité de propagation des ondes sonores est bien établie expérimentalement par la similitude d'effet que produit une musique donnée à toutes distances du lieu où l'on l'exécute. La principale difficulté, je dirai l'unique difficulté qu'on eût élevée contre le système des ondes, consistait donc à expliquer comment la vitesse de propagation des rayons de différentes couleurs dans des corps différents pouvait être dissemblable et servir à rendre compte de l'inégalité de réfraction de ces rayons ou de la dispersion. On a montré récemment que cette difficulté n'est pas insurmontable; qu'on peut constituer l'Ether dans les corps inégalement denses de manière que des rayons à ondulations dissemblables s'y *propagent* avec des vitesses inégales: reste à déterminer si les conceptions des géomètres à cet égard sont conformes à la nature des choses. Voici les amplitudes des ondulations déduites expérimentalement d'une série de faits relatifs aux interférences:—

| | *Millimètres.* |
|---|---|
| Violet . . . . . . . | 0·000423 |
| Jaune . . . . . . . | 0·000551 |
| Rouge . . . . . . . | 0·000620 |

La vitesse de transmission des rayons de différentes couleurs dans les espaces célestes est la même dans le système des ondes, et tout-à-fait indépendante de l'étendue ou de la vitesse des ondulations" (Arago, MSS. 1849). Compare also Annuaire pour 1842, p. 333—336. The length of the luminous wave of the ether and the rapidity of the vibrations determine the character of the coloured rays. The violet, which is the most refrangible ray, has 662, and red, which (with the greatest length of wave) is the least refrangible ray, has only 451, billions of vibrations in a second.

(144) p. 75.—"J'ai prouvé, il y a bien des années, par des observations directes, que les rayons des étoiles vers lesquelles la Terre marche, et les rayons des étoiles dont la Terre s'éloigne, se réfractent exactement de la même quantité. Un tel résultat ne peut se concilier avec *la théorie de l'émission* qu'à l'aide d'une addition importante à faire à cette théorie: il faut admettre que les corps lumineux émettent des rayons de toutes les vitesses, et que les seuls

rayons d'une vitesse déterminée sont visibles, qu'eux seuls produisent dans l'œil la sensation de lumière. Dans la théorie de l'émission, le rouge, le jaune, le vert, le bleu, le violet solaires sont respectivement accompagnés de rayons pareils, mais obscurs par défaut ou par excès de vitesse. A plus de vitesse correspond une moindre réfraction, comme moins de vitesse entraine une réfraction plus grande. Ainsi chaque rayon rouge visible est accompagné de rayons obscurs de la même nature, qui se réfractent les uns plus, les autres moins que lui : ainsi il *existe des rayons dans les stries noires* de la portion rouge du spectre; la même chose doit être admise des stries situées dans les portions jaunes, vertes, bleues et violettes"—Arago, in the Comptes rendus de l'Acad. des Sciences, T. xvi. 1843, p. 404. (Compare also T. viii. 1839, p. 326; and Poisson, Traité de Mécanique, éd. 2, 1833, T. i. § 168.) According to the undulatory theory, the heavenly bodies send out waves of infinitely different velocities of transverse vibration.

([145]) p. 75.—Wheatstone, in the Phil. Trans. of the Royal Society for 1834, p. 589 and 591. From the experiments described in this memoir, it appears to follow that the human eye is capable of receiving impressions from luminous phænomena, of which the duration is limited to one-millionth part of a second (p. 591). On the hypothesis alluded to in the text, according to which the Sun's light is analogous to the Earth's polar light, see Sir John Herschel, Results of Astron. Observ. at the Cape of Good Hope, 1847, p. 351. The ingenious application of Wheatstone's revolving apparatus, improved by Breguet, to a critical experiment in the decision between the emission and undulatory theories,—as, according to the former, light should pass quicker, and according to the latter slower, through water than through air,—has already been spoken of by Arago in the Comptes rendus, T. vii. 1838, p. 956. (Compare Comptes rendus pour 1850, T. xxx. p. 489—495 and 556.)

([146]) p. 77.—Steinheil, in Schumacher's Astr. Nachr. No. 679 (1849), S. 97—100; Walker, in the Proceedings of the American Philosophical Society, Vol. v. p. 128 (compare older propositions of Pouillet, in the Comptes rendus, T. xix. p. 1386). Still later ingenious experiments of Mitchel, Director of the Observatory of Cincinnati (Gould's Astron. Journal, Dec. 1849, p. 3, on the Velocity of the Electric Wave), and of Fizeau and Gounelle at Paris (April 1850), differ from Wheatstone's and Walker's results. Striking differences between iron and copper, in respect to conduction, are shown by experiments given in the Comptes rendus, T. xxx. p. 439.

([147]) p. 77.—See Poggendorff, in his Annalen, Bd. lxxiii. 1848, S. 337; and Pouillet, Comptes rendus, T. xxx. p. 501.

([148]) p. 77.—Riess, in Poggen. Ann. Bd. 78, S. 433. On the non-conduction through the earth, see the important experiments of Guillemin "sur le courant dans une pile isolée, et sans communication entre les pôles," in the Comptes rendus, T. xxix. p. 521. "Quand on remplace un fil par la terre dans les télégraphes électriques, la terre sert plutót de réservoir commun que de moyen d'union entre les deux extrémités du fil."

([149]) p. 78.—Mädler, Astr. S. 380. Laplace, according to Moigno, Répertoire d'Optique moderne, 1847, T. i. p. 72:—"Selon la théorie de l'émission, on croit pouvoir démontrer que si le diamètre d'une étoile fixe serait 250 fois plus grand que celui du soleil, sa densité restant la même, l'attraction exercée à sa surface détruirait la quantité de mouvement de la molécule lumineuse émise, de sorte qu'elle serait invisible à de grandes distances." If, with William Herschel, we ascribe to Arcturus an apparent diameter of $0''\cdot1$, it would follow from this assumption that the actual diameter of this star is only 11 times greater than that of our Sun (Kosmos, Bd. i. S. 153 and 415; English edition, p. 137—138, and Note 107). According to the above view of one of the causes of non-luminosity, it would follow that, with very different dimensions of the heavenly bodies, the velocity of their light would be also very different, which hitherto has by no means been confirmed by observation. (Arago, in the Comptes rendus, T. viii. p. 326, says:—"Les expériences sur l'égale déviation prismatique des étoiles vers lesquelles la terre marche ou dont elle s'éloigne, rend compte de l'égalité de vitesse apparente des rayons de toutes les étoiles.")

([150]) p. 79.—Eratosthenes, Catasterismi, ed. Schaubach, 1795; and Eratosthenica, ed. God. Bernhardy, 1822, p. 110—116. The description distinguishes among stars *λαμπροὺς* (*μεγάλους*) and *ἀμαυροὺς* (cap. 2, 11, 41). So also Ptolemy: with whom *οἱ ἀμόρφωτοι* relate only to stars which are not included *formally* in a constellation.

([151]) p. 80.—Ptol. Almag. ed. Halma, T. ii. p. 40; and in Eratosth. Catast. cap. 22, p. 18: *ή δε κεφαλὴ καὶ ἡ ἅρπη ἄναπτος ὁρᾶται, διὰ δὲ νεφελώδους συστροφῆς δοκεῖ τισιν ὁρᾶσθαι.* So also Geminus, Phæn. (ed. Hilder. 1590), p. 46.

([152]) p. 80.—Kosmos, Bd. ii. S. 369 and 514 (Anm. 63); English edition, p. 328 and cxviii. (Note 503).

([153]) p. 80.—Muhamedis Alfragani Chronologica et Astr. Elementa, 1590, cap. xxiv. p. 118.

([154]) p. 81.—Some manuscripts of the Almagest point to such sub-divisions or intermediate classes, as they add to the determinations of magnitude the

words μειζων or ἐλάσσων (Cod. Par. N° 2389). Tycho Brahe expressed this increasing or diminishing by points.

(155) p. 81.—Sir John Herschel, Outl. of Astr. p. 520—527.

(156) p. 82.—This was the application of mirror sextants to the determination of the light of stars which I employed in the tropics still more than diaphragms, which had been recommended to me by Borda. I began the work under the fine sky of Cumana, and continued it subsequently up to 1803, under less favourable circumstances, on the high plains of the Andes, and on the coast of the Pacific at Guayaquil. I had formed for myself an arbitrary scale, in which I made Sirius, as the brightest of all the fixed stars, = 100; stars of the 1st magnitude between 100 and 80; 2d magnitude between 80 and 60; 3d magnitude between 60 and 45; 4th between 45 and 30; and 5th between 30 and 20. I passed in review more particularly the constellations of Argo and Grus, in which I believed I should find alterations since Lacaille's time. It appeared to me, after careful combinations of estimation, and employing other stars as intermediate gradations, that Sirius is as much superior in the strength of its light to Canopus, as α Centauri is to Achernar. On account of the above-mentioned mode of classification, my numbers do not admit of direct comparison with those given since 1838 by Sir John Herschel. (See my Recueil d'Observ. astr. Vol. i. p. lxxi.; and Relat. hist. du Voy. aux Régions équin. T. i. p. 518 and 624; also Lettre de M. de Humboldt à M. Schumacher en Févr. 1839, in the Astr. Nachr. N° 374.) In this letter I say:—"M. Arago, qui possède des moyens photométriques entièrement différents de ceux qui ont été publiés jusqu'ici, m'avait rassuré sur la partie des erreurs qui pouvaient provenir du changement d'inclinaison d'un miroir entamé sur la face intérieure. Il blame d'ailleurs le principe de ma méthode, et le regarde comme peu susceptible de perfectionnement, non-seulement à cause de la différence des angles entre l'étoile vue directement et celle qui est amenée par reflexion, mais surtout parce que le résultat de la mésure d'intensité dépend de la partie de l'œil qui se trouve en face de l'oculaire. Il y a erreur lorsque la pupille n'est pas très-exactement à la hauteur de la limite inférieure de la portion non entamée du petit miroir."

(157) p. 82.—Compare Steinheil, Elemente der Helligkeit's-Messungen am Sternenhimmel München, 1836 (Schum. Astr. Nachr. No. 609) and John Herschel, Results of Astronomical Observations made during the years 1834—1838 at the Cape of Good Hope (Lond. 1847), p. 353—357. In 1846,

Seidel attempted to determine with Steinheil's photometer the quantities of light of several stars of the 1st magnitude which appear at sufficient altitudes in our northern hemisphere. He makes *α* Lyræ = 1, and then finds Sirius = 5·13; Rigel, whose brightness seems to be increasing, = 1·30; Arcturus, 0·84; Capella, 0·83; Procyon, 0·71; Spica, 0·49; Atair, 0·40; Aldebaran 0·36; Deneb, 0·35; Regulus, 0·34; Pollux, 0·30; Betelgeuze is left out, because it is variable, as appeared particularly between 1836 and 1839 (Outlines, p. 523).

(158) p. 83.—For the numerical bases of the photometric results, compare four tables of Sir John Herschel, in his Cape Observations (*a.* p. 341; *b.* p. 367—371; *c.* p. 440; and *d.* in his Outlines of Astronomy, p. 522—525, and 645—646). For a mere arrangement in order of magnitude or brightness, but without any numbers being expressed, see the Manual of Scientific Enquiry prepared for the Use of the Navy, 1849, p. 12. In order to render more complete the conventional language which has been hitherto used (*i. e.* the old classification into magnitudes), Sir John Herschel, in the Outlines of Astronomy, p. 645, has appended to the vulgar scale of magnitudes, a scale of photometric magnitudes obtained merely by the addition of 0·41, as is more fully explained in the Cape Observations, p. 370. I subjoin such a table, combining in it the stars of the Northern and Southern Hemispheres without distinction. See p. xlii. to p. xlv. at the close of the Notes belonging to this section.

(159) p. 83.—Argelander, Durchmusterung des nördl. Himmels zwischen 45° und 80° Decl. 1846, S. xxiv.—xxvi.; Sir John Herschel, Ast. Obs. at the Cape of Good Hope, p. 327, 340, and 365.

(160) p. 83.—Same work, p. 304; and Outlines, p. 522.

(161) p. 84.—Phil. Trans. Vol. lvii. for the year 1767, p. 234.

(162) p. 84.—Wollaston's comparison of the light of the Sun and of the Moon was made in 1799, and was based on shadows cast by wax-lights, while in the experiments with Sirius in 1826 and 1827 images reflected from a glass-globe were employed. The earlier assigned ratios of the intensity of the solar light as compared to that of the Moon differ very much from the results here given. Michell and Euler, proceeding from theoretical grounds, had respectively concluded 450000 and 374000 to 1. Bouguer, from measurements of the shadows of wax-lights, had even made it only 300000 to 1. Lambert considers the light of Venus, when at the brightest, to be 3000 fainter than that of the full Moon. According to Steinheil, the Sun would require to be 3286500 times further off than it is in order to appear to the inhabitants of

the Earth like Arcturus (Struve, Stellarum compositarum mensuræ micrometricæ, p. clxiii.); and Arcturus, according to Sir John Herschel, has for us only half the strength of light of Canopus (Herschel, Observations at the Cape, p. 34). All these ratios of intensity, and particularly the important comparison of the Sun, the full Moon, and the ashy light of our satellite, so different according to its position in reference to the reflecting Earth, deserve a final and much more serious examination.

(163) p. 84.—Outl. of Astr. p. 553; Astr. Observ. at the Cape, p. 363.

(164) p. 85.—William Herschel on the Nature of the Sun and Fixed Stars, in the Phil. Trans. for 1795, p. 62, and on the changes that happen to the fixed stars, in the Phil. Trans. for 1796, p. 186. Compare also Sir John Herschel, Observ. at the Cape, p. 350—352.

(165) p. 85.—Extrait d'une lettre de M. Arago à M. de Humboldt (Mai 1850):—

"a. *Mesures photométriques.*

"Il n'existe pas de photomètre proprement dit, c'est-à-dire d'instrument donnant l'intensité d'une lumière isolée; le photomètre de Leslie, à l'aide duquel il avait eu l'audace de vouloir comparer la lumière de la lune à la lumière du soleil, par des actions calorifiques, est complètement defectueux. J'ai prouvé en effet, que ce prétendu photomètre monte quand on l'expose à la lumière du soleil, qu'il descend sous l'action de la lumière du feu ordinaire, et qu'il reste complètement stationnaire lorsqu'il reçoit la lumière d'une lampe d'Argand. Tout ce qu'on a pu faire jusqu'ici, c'est de comparer entr'elles deux lumières en présence, et cette comparaison n'est même à l'abri de toute objection que lorsqu'on ramène ces deux lumières à l'égalité par un affaiblissement graduel de la lumière la plus forte. C'est comme critérium de cette égalité que j'ai employé les anneaux colorés. Si on place l'une sur l'autre deux lentilles d'un long foyer, il se forme autour de leur point de contact des anneaux colorés tant par voie de réflexion que par voie de transmission. Les anneaux réflechis sont complémentaires en couleur des anneaux transmis; ces deux séries d'anneaux se neutralisent mutuellement quand les deux lumières qui les forment et qui arrivent simultanément sur les deux lentilles, sont égales entr'elles.

"Dans le cas contraire on voit des traces ou d'anneaux réfléchis ou d'anneaux transmis, suivant que la lumière qui forme les premiers, est plus forte ou plus faible que la lumière à laquelle on doit les seconds. C'est dans ce sens seulement que les anneaux colorés jouent un rôle dans les mesures de la lumière auxquelle je me suis livré.

" b. *Cyanomètre.*

" Mon cyanomètre est une extension de mon polariscope. Ce dernier instrument, comme tu sais, se compose d'un tube fermé à l'une de ses extrémités par une plaque de cristal de roche perpendiculaire à l'axe, de 5 millemètres d'épaisseur ; et d'un prisme doué de la double refraction, placé du coté de l'œil. Parmi les couleurs variées que donne cet appareil, lorsque de la lumière polarisée le traverse, et qu'on fait tourner le prisme sur lui-même, se trouve par un heureux hasard la nuance du bleu de ciel. Cette couleur bleue fort affaiblie, c'est-à-dire très mélangée de blanc lorsque la lumière est presque neutre, augmente d'intensité—progressivement à mesure que les rayons qui pénètrent dans l'instrument, renferment une plus grande proportion de rayons polarisés.

" Supposons donc que le polariscope soit dirigé sur une feuille de papier blanc ; qu'entre cette feuille et la lame de cristal de roche il existe une pile de plaques de verre susceptible de changer d'inclinaison, ce qui rendra la lumière éclairante du papier plus ou moins polarisée ; la couleur bleue fournie par l'instrument va en augmentant avec l'inclinaison de la pile, et l'on s'arrête lorsque cette couleur parait la même que celle de la région de l'atmosphère dont on veut déterminer la teinte cyanométrique, et qu'on regarde à l'œil nu immédiatement à côté de l'instrument. La mesure de cette teinte est donnée par l'inclinaison de la pile. Si cette dernière partie de l'instrument se compose du même nombre de plaques et d'une même espèce de verre, les observations faites dans divers lieux seront parfaitement comparables entr'elles."

([166]) p. 85.—Argelander de fide Uranometriæ Bayeri, 1842, p. 14—23 : " in eadem classe littera prior majorem splendorem nullo modo indicat" (§ 9). According to this it is by no means proved by Bayer's authority that Castor was brighter in 1603 than Pollux.

## PHOTOMETRIC ARRANGEMENT OF THE FIXED STARS.

I CONCLUDE this section with a table taken from Sir John Herschel's Outlines of Astronomy (p. 645 and 646): I am indebted for its arrangement and lucid explanation to my learned friend, Dr. Galle, from whose letter to myself, dated in March 1850, I subjoin the following extract:—

"The numbers in the Photometric Scale in the Outlines of Astronomy are results obtained from the 'Vulgar Scale,' by an addition throughout of 0·41. The author (Sir John Herschel) has arrived at these more exact determinations of star-magnitudes by observed 'sequences' of brightness, and by the combination of these observations with the average of the assigned magnitudes in ordinary use (Cape Observations, p. 304—352), taking more particularly the data in the Astronomical Society's Catalogue for 1827 as a basis. The proper photometric results of several stars by means of the Astrometer (Cape Observations, p. 353, *et seq.*) have not been employed directly in this table, but have only served in a general way as a means of judging of the relation or correspondence of the scale in common use (1st, 2d, 3d, &c. magnitudes), to the real quantities of light in different stars. There has thus been found the result (at all events remarkable), that the decrease of our ordinary star-magnitudes (1, 2, 3......) is approximately as if a star of the 1st magnitude were placed successively at distances of 1, 2, 3, ..... whereby, according to photometric law, its brightness would have successively the values 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$...... (Cape Observations, p. 371, 372; Outlines, p. 521, 522); but in order to make accordance still greater, it is only necessary to raise our star-magnitudes, as hitherto employed, about half a magnitude (or more exactly 0·41); so that in future a star of the 2·00 magnitude should be called of the 2·41 magnitude; a star of 2·5 magnitude, 2·91, and so on. Sir John Herschel has proposed this 'photometric' (raised) scale for acceptance (Cape Obs. p. 372; Outl. p. 522), and his proposal will surely be assented to: for, the difference from the Common or Vulgar Scale would 'hardly be felt' (Cape Obs. p. 372); and the table in the 'Outlines of Astronomy,' p. 645, *et seq.*, may already serve as a basis as far

down as the 4th magnitude. The determination of magnitudes of stars according to this rule—viz. that the brightnesses of stars of the 1, 2, 3, 4...... magnitudes should be to each other in the ratio of 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$......exactly, as they already are approximately,—is thus already in part practicable. Sir John Herschel (Outlines, p. 523; Cape Obs. p. 372) takes $\alpha$ Centauri as a normal star for the 1st magnitude of the Photometric Scale, and as the unit for the quantity of light. If, therefore, we square the photometric magnitude of a star, we have the inverse ratio of its quantity of light to that of $\alpha$ Centauri. So, for example, if $\kappa$ Orionis is of photometric magnitude 3, it has $\frac{1}{9}$ of the light of $\alpha$ Centauri. At the same time, the number 3 would show $\kappa$ Orionis to be 3 times as far from us as $\alpha$ Centauri, if we assume the two stars to be bodies equal in real magnitude and brightness. If another star—*ex. gr.* Sirius, which is four times as bright—had been chosen as the unit of the photometric magnitudes indicating distances, the regular conformity to law would not have been seen with so much simplicity. Nor is it without interest that the distance of $\alpha$ Centauri is known with some probability, and that among the distances of fixed stars which have yet been investigated it is the least. The author treats in the Outlines, p. 521, of the inferiority, in point of suitability, of other scales as compared with the photometric one, which advances according to the squares 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$....... He also notices geometrical progressions—as, for example, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$......or 1, $\frac{1}{3}$, $\frac{1}{9}$, $\frac{1}{27}$...... The gradations which you selected in the Observations at the Equator in your American Expedition follow an arithmetical progression (Recueil d'Observ. astron. Vol. 1, p. lxxi.; and Schumacher, Astron. Nachr. No. 374). All these scales adapt themselves less well to the vulgar scale than to the photometric (quadratic) progression." In the following table, the 190 stars of the "Outlines of Astronomy" are arranged solely according to their magnitudes, without regard to South or North Declination.

List of 190 STARS of the First, Second, and Third Magnitudes, arranged according to the determinations of Sir JOHN HERSCHEL, and giving the ordinary or "vulgar" magnitudes with greater exactness than usual; as well as the *photometric* scale proposed by him.

STARS OF THE FIRST MAGNITUDE.

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| Sirius . . | 0.08 | 0.49 | α Orionis . . | 1.0 : | 1.43 |
| η Argûs (Var.) | — | — | α Eridani . . | 1.09 | 1.50 |
| Canopus . . | 0.29 | 0.70 | Aldebaran . | 1.1 : | 1.5 : |
| α Centauri . . | 0.59 | 1.00 | β Centauri . . | 1.17 | 1.58 |
| Arcturus . . | 0.77 | 1.18 | α Crucis . . | 1.2 | 1.6 |
| Rigel . . . | 0.82 | 1.23 | Antares . . | 1.2 | 1.6 |
| Capella . . | 1.0 : | 1.4 : | α Aquilæ . . | 1.28 | 1.69 |
| α Lyræ . . . | 1.0 : | 1.4 : | Spica . . . | 1.38 | 1.79 |
| Procyon . . | 1.0 : | 1.4 : | | | |

STARS OF THE SECOND MAGNITUDE.

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| Fomalhaut . | 1.54 | 1.95 | α Ursæ (Var.) . | 1.96 | 2.37 |
| β Crucis . . | 1.57 | 1.98 | ζ Orionis . . | 2.01 | 2.42 |
| Pollux . . | 1.6 : | 2.0 : | β Argûs . . . | 2.03 | 2.44 |
| Regulus . . | 1.6 : | 2.0 : | α Persei . . . | 2.07 | 2.48 |
| α Gruis . . . | 1.66 | 2.07 | γ Argûs . . . | 2.08 | 2.49 |
| γ Crucis . . | 1.73 | 2.14 | ε Argûs . . . | 2.18 | 2.59 |
| ε Orionis . . | 1.84 | 2.25 | η Ursæ (Var.) . | 2.18 | 2.59 |
| ε Canis . . . | 1.86 | 2.27 | γ Orionis . . | 2.18 | 2.59 |
| λ Scorpii . . | 1.87 | 2.28 | α Triang. austr. | 2.23 | 2.64 |
| α Cygni . . . | 1.90 | 2.31 | ε Sagittarii . . | 2.26 | 2.67 |
| Castor . . | 1.94 | 2.35 | β Tauri . . . | 2.28 | 2.69 |
| ε Ursæ (Var.) . | 1.95 | 2.36 | Polaris . . | 2.28 | 2.69 |

### Stars of the Second Magnitude—*continued.*

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| ϑ Scorpii . . | 2.29 | 2.70 | δ Argûs . . . | 2.42 | 2.83 |
| α Hydræ . . | 2.30 | 2.71 | ζ Ursæ . . . | 2.43 | 2.84 |
| δ Canis . . . | 2.32 | 2.73 | β Andromedæ . | 2.45 | 2.86 |
| α Pavonis . . | 2.33 | 2.74 | β Ceti . . . | 2.46 | 2.87 |
| γ Leonis . . | 2.34 | 2.75 | λ Argûs . . . | 2.46 | 2.87 |
| β Gruis . . . | 2.36 | 2.77 | β Aurigæ . . | 2.48 | 2.89 |
| α Arietis . . | 2.40 | 2.81 | γ Andromedæ . | 2.50 | 2.91 |
| σ Sagittarii . . | 2.41 | 2.82 | | | |

### Stars of the Third Magnitude.

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| γ Cassiopeiæ . | 2.52 | 2.93 | ε Scorpii . . | 2.71 | 3.12 |
| α Andromedæ . | 2.54 | 2.95 | ζ Argûs . . . | 2.72 | 3.13 |
| ϑ Centauri . . | 2.54 | 2.95 | β Ursæ . . . | 2.77 | 3.18 |
| α Cassiopeiæ . | 2.57 | 2.98 | α Phœnicis . . | 2.78 | 3.19 |
| β Canis . . . | 2.58 | 2.99 | ι Argûs . . . | 2.80 | 3.21 |
| χ Orionis . . | 2.59 | 3.00 | ε Boötis . . | 2.80 | 3.21 |
| γ Geminorum . | 2.59 | 3.00 | α Lupi . . . | 2.82 | 3.23 |
| δ Orionis . . | 2.61 | 3.02 | ε Centauri . . | 2.82 | 3.23 |
| Algol (Var.) . | 2.62 | 3.03 | η Canis . . . | 2.85 | 3.26 |
| ε Pegasi . . | 2.62 | 3.03 | β Aquarii . . | 2.85 | 3.26 |
| γ Draconis . . | 2.62 | 3.03 | δ Scorpii . . | 2.86 | 3.27 |
| β Leonis . . | 2.63 | 3.04 | ε Cygni . . . | 2.88 | 3.29 |
| α Ophiuchi . . | 2.63 | 3.04 | η Ophiuchi . . | 2.89 | 3.30 |
| β Cassiopeiæ . | 2.63 | 3.04 | γ Corvi . . . | 2.90 | 3.31 |
| γ Cygni . . . | 2.63 | 3.04 | α Cephei . . | 2.90 | 3.31 |
| α Pegasi . . | 2.65 | 3.06 | η Centauri . . | 2.91 | 3.32 |
| β Pegasi . . | 2.65 | 3.06 | α Serpentis . . | 2.92 | 3.33 |
| γ Centauri . . | 2.68 | 3.09 | δ Leonis . . | 2.94 | 3.35 |
| α Coronæ . . | 2.69 | 3.10 | χ Argûs . . . | 2.94 | 3.35 |
| γ Ursæ . . . | 2.71 | 3.12 | β Corvi . . . | 2.95 | 3.36 |

STARS OF THE THIRD MAGNITUDE—*continued.*

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| β Scorpii | 2.96 | 3.37 | ϑ Argûs | 3.26 | 3.67 |
| ζ Centauri | 2.96 | 3.37 | β Hydri | 3.27 | 3.68 |
| ζ Ophiuchi | 2.97 | 3.38 | ζ Persei | 3.27 | 3.68 |
| α Aquarii | 2.97 | 3.38 | ζ Herculis | 3.28 | 3.69 |
| π Argûs | 2.98 | 3.39 | ε Corvi | 3.28 | 3.69 |
| γ Aquilæ | 2.98 | 3.39 | ι Aurigæ | 3.29 | 3.70 |
| δ Cassiopeiæ | 2.99 | 3.40 | γ Urs. min. | 3.30 | 3.71 |
| δ Centauri | 2.99 | 3.40 | η Pegasi | 3.31 | 3.72 |
| α Leporis | 3.00 | 3.41 | β Aræ | 3.31 | 3.72 |
| δ Ophiuchi | 3.00 | 3.41 | α Toucani | 3.32 | 3.73 |
| ζ Sagittarii | 3.01 | 3.42 | β Capricorni | 3.32 | 3.73 |
| η Boötis | 3.01 | 3.42 | ρ Argûs | 3.32 | 3.73 |
| η Draconis | 3.02 | 3.43 | ζ Aquilæ | 3.32 | 3.73 |
| π Ophiuchi | 3.05 | 3.46 | β Cygni | 3.33 | 3.74 |
| β Draconis | 3.06 | 3.47 | γ Persei | 3.34 | 3.75 |
| β Libræ | 3.07 | 3.48 | μ Ursæ | 3.35 | 3.76 |
| γ Virginis | 3.08 | 3.49 | β Triang. bor. | 3.35 | 3.76 |
| μ Argûs | 3.08 | 3.49 | π Scorpii | 3.35 | 3.76 |
| β Arietis | 3.09 | 3.50 | β Leporis | 3.35 | 3.76 |
| γ Pegasi | 3.11 | 3.52 | γ Lupi | 3.36 | 3.77 |
| δ Sagittarii | 3.11 | 3.52 | δ Persei | 3.36 | 3.77 |
| α Libræ | 3.12 | 3.53 | ψ Ursæ | 3.36 | 3.77 |
| λ Sagittarii | 3.13 | 3.54 | ε Aurigæ (Var.) | 3.37 | 3.78 |
| β Lupi | 3.14 | 3.55 | υ Scorpii | 3.37 | 3.78 |
| ε Virginis ? | 3.14 | 3.55 | ι Orionis | 3.37 | 3.78 |
| α Columbæ | 3.15 | 3.56 | γ Lyncis | 3.39 | 3.80 |
| ϑ Aurigæ | 3.17 | 3.58 | ζ Draconis | 3.40 | 3.81 |
| β Herculis | 3.18 | 3.59 | α Aræ | 3.40 | 3.81 |
| ι Centauri | 3.20 | 3.61 | π Sagittarii | 3.40 | 3.81 |
| δ Capricorni | 3.20 | 3.61 | π Herculis | 3.41 | 3.82 |
| δ Corvi | 3.22 | 3.63 | β Can. min. ? | 3.41 | 3.82 |
| α Can. ven. | 3.22 | 3.63 | ζ Tauri | 3.42 | 3.83 |
| β Ophiuchi | 3.23 | 3.64 | δ Draconis | 3.42 | 3.83 |
| δ Cygni | 3.24 | 3.65 | μ Geminorum | 3.42 | 3.83 |
| ε Persei | 3.26 | 3 67 | γ Boötis | 3.43 | 3.84 |
| η Tauri ? | 3.26 | 3.67 | ε Geminorum | 3.43 | 3.84 |
| β Eridani | 3.26 | 3.67 | α Muscæ | 3.43 | 3.84 |

STARS OF THE THIRD MAGNITUDE—*continued.*

| Star. | Vulgar Scale. | Photo. Scale. | Star. | Vulgar Scale. | Photo. Scale. |
|---|---|---|---|---|---|
| α Hydri ? . . | 3.44 | 3.85 | ι Ursæ . . . | 3.46 | 3.87 |
| τ Scorpii . . | 3.44 | 3.85 | η Aurigæ . . | 3.46 | 3.87 |
| δ Herculis . . | 3.44 | 3.85 | γ Lyræ . . . | 3.47 | 3.88 |
| δ Geminorum . | 3.44 | 3.85 | η Geminorum . | 3.48 | 3.89 |
| q Orionis . . | 3.45 | 3.86 | γ Cephei . . | 3.48 | 3.89 |
| β Cephei . . | 3.45 | 3.86 | κ Ursæ . . . | 3.49 | 3.90 |
| ϑ Ursæ . . . | 3.45 | 3.86 | ε Cassiopeiæ . | 3.49 | 3.90 |
| ζ Hydræ . . | 3.45 | 3.86 | ϑ Aquilæ . . | 3.50 | 3.91 |
| γ Hydræ . . | 3.46 | 3.87 | σ Scorpii . . | 3.50 | 3.91 |
| β Triang. austr. | 3.46 | 3.87 | τ Argûs . . . | 3.50 | 3.91 |

"The following statement of the Quantities of Light in 17 Stars of the First Magnitude (as they follow from the *photometric* magnitudes) may possess some interest:—

| | | | |
|---|---|---|---|
| Sirius . . . . | 4.165 | α Orionis . . . . | 0.489 |
| η Argûs . . . . | — | α Eridani . . . . | 0.444 |
| Canopus . . . . | 2.041 | Aldebaran . . . | 0.444 |
| α Centauri . . . . | 1.000 | β Centauri . . . . | 0.401 |
| Arcturus . . . . | 0.718 | α Crucis . . . . | 0.391 |
| Rigel . . . . . | 0.661 | Antares . . . . | 0.391 |
| Capella . . . . | 0.510 | α Aquilæ . . . . | 0.350 |
| α Lyræ . . . . . | 0.510 | Spica . . . . . | 0.312 |
| Procyon . . . . | 0.510 | | |

as may also the Quantities of Light in Stars which are *exactly* of the First to the Sixth Magnitudes:

| Magnitude according to the vulgar scale. | Quantity of light. |
|---|---|
| 1.00 | 0.500 |
| 2.00 | 0.172 |
| 3.00 | 0.086 |
| 4.00 | 0.051 |
| 5.00 | 0.034 |
| 6.00 | 0.024 |

the quantity of light in α Centauri being the unit throughout.'

([167]) p. 86.—Kosmos, Bd. iii. S. 49 and 57, Anm. 32 and 33 (English edition, p. 39, and Notes 78 and 79).

([168]) p. 87.—Kosmos, Bd. i. S. 185 and 428, Anm. 14 (English edition, p. 168, Note 144).

([169]) p. 89.—On the Space-penetrating Power of Telescopes, in Sir John Herschel's Outl. of Astr. § 803.

([170]) p. 89.—I cannot attempt to compress within the limits of a note *all* the reasons upon which Argelander's views are founded. It will be sufficient for me to insert the following extracts from some of his letters to myself:—"A few years ago (1843) you requested Captain Schwink to estimate for you the number of stars visible on the whole celestial vault, from the 1st to the 7th magnitude inclusive, according to the proportion of those entered in his Mappa cœlestis. He finds 12148 stars between −30° and +90° Decl.; consequently, assuming the same frequency of stars from −30° Decl. to the South Pole, there would be in the entire firmament 16200 stars of the above-named magnitudes. This estimation seems to me also to come very near the truth. We know that, if we only consider the general mass, each successive class or magnitude contains about three times as many stars as the preceding one (Struve, Catalogus Stellarum duplicium, p. xxxiv.; Argelander, Bonner Zonen, S. xxvi.) Now in my Uranomètrie I have 1441 stars of the 6th magnitude North of the Equator, whence there would follow, for the entire heavens, about 3000; but this does not include stars of the 6·7 magnitude, which yet, if whole classes only were counted, would be reckoned as belonging to the 6th class. I think we might take these at 1000: so that we should have 4000 stars of the 6th magnitude; and thus, according to the above-mentioned rule, 12000 stars of the 7th magnitude,—or 18000 stars from the 1st to the 7th magnitude inclusive. I arrive at a rather more exact conclusion, by means of other considerations respecting the number of stars of the 7th magnitude which I have marked in my zones, viz. 2251 (pag. xxvi.); having regard to stars which have been observed more than once, and to those which have probably been overlooked. In this way I find, between 45° and 80° North Decl., 2340 stars of the 7th magnitude, and thence, over the whole heavens, about 17000 stars. Struve, in the Description de l'Observatoire de Poulkova, p. 268, gives the number of stars down to the 7th magnitude, in the region of the heavens examined by him (*i. e.* −15° to +90°), 13400; whence there would follow, for the entire heavens, 21300. According to the Introduction to Weisse's Catal. e Zonis Regiomontanis ded. p. xxxii., Struve finds, by the calculus of probabilities, 3903 stars from the

1st to the 7th magnitude in the zone from $-15°$ to $+15°$; whence, in the whole heavens, 15050 such stars. This number is less than mine, because Bessel estimated the brighter stars about half a magnitude lower than I did. It is only a mean number which we can look for here; and this we might take, therefore, at 18000 stars from the 1st to the 7th magnitude inclusive. In the passage of the Outlines of Astronomy, p. 521, of which you remind me, Sir John Herschel speaks only of the stars already registered: 'The whole number of stars already registered, down to the 7th magnitude inclusive, amounting to from 12000 to 15000.' As respects the fainter stars of the 8th and 9th magnitudes, Struve finds, in the above-mentioned zone of $-15°$ to $+15°$, of stars of the 8th magnitude, 10557; and of stars of the 9th magnitude, 37739: consequently, for the whole heavens, 40800 stars of the 8th, and 145800 stars of the 9th magnitude. Thus we should have, according to Struve, from the 1st to the 9th magnitude inclusive, $15100+40800+145800=201700$ stars. These numbers were found by Struve by carefully comparing those zones or parts of zones which included the same parts of the heavens; and from the number of stars common to them, and the number of those which were different, concluding, by the calculus of probabilities, the number of stars actually existing. This calculation deserves very great confidence, as a large number of stars have contributed to form its basis. Bessel has entered in the whole of his zones between $-15°$ and $+45°$, about 61000 different stars from the 1st to the 9th magnitude inclusive (after deducting stars observed more than once, and stars of 9·10 magnitude); whence, taking into account those which have been probably overlooked, there would follow, for the part of the heavens which has been mentioned, about 101500 of the magnitudes in question. My zones between $+45°$ and $+80°$ contain about 22000 different stars (Durchmusterung des nördl. Himmels, S. xxv.): from this number we must deduct about 3000 of the 9·10 magnitude; leaving 19000. My zones are somewhat richer than Bessel's, and I do not think I can assume more than 28500 as the number of actually existing stars within their limits (between $+45°$ and $+80°$): so that we should have 130000, to the 9th magnitude inclusive, between $-15°$ and $+80°$. This is about 0·62181 of the entire heavens; so that, assuming a generally equable distribution, we should have over the entire firmament 209000 stars, or thus again nearly the same number as that assigned by Struve: perhaps even it may be one not inconsiderably greater, as Struve has reckoned the stars of 9·10 magnitude as belonging to the 9th magnitude. The numbers which, according to my views, I should say

might be assumed for the entire heavens, would thus be—1st mag. 20, 2d mag. 65, 3d mag 190, 4th mag. 425, 5th mag. 1100, 6th mag. 3200, 7th mag. 13000, 8th mag. 40000, 9th mag. 142000; making together, from the 1st to the 9th magnitudes inclusive, 200000 stars. If you should object to me, that Lalande (Hist. céleste, p. iv.) gives the number of stars visible to the naked eye, observed by himself, at 6000, I should remark in reply that there are amongst them very many observed more than once; and that, omitting these, we arrive approximately at only 3800 stars for the part of the heavens comprised by Lalande's observations—*i. e.* between $-26° 30'$ and $+90°$. As this is 0·72310 of the entire heavens, the resulting number of stars visible to the naked eye throughout the firmament would again be 5255. A review of the Uranography of Bode, composed from very heterogeneous elements (17240 stars), after deducting nebulæ and smaller stars, as well as stars of 6·7 magnitude raised to the 6th magnitude, gives not above 5600 stars from the 1st to the 6th magnitude inclusive. A similar estimation for the whole heavens, corresponding to the number of stars from the 1st to the 6th magnitude inclusive, registered by Lacaille, between the South Pole and the Tropic of Capricorn, confirms also the mean result previously given to you, since it falls between the limits of 3960 and 5900. You see that I have willingly endeavoured to fulfil your wish for a more thorough investigation of the numbers. I may add that Heis, of Aix-la-Chapelle, has been for several years engaged in an exceedingly careful revision of my Uranomètrie. According to the portion of this work which is already completed, and according to the considerable augmentations which have been made to my Uranomètrie by an observer gifted with more acute vision, I find for the Northern Hemisphere 2836 stars from the 1st to the 6th magnitude inclusive: and hence, on the assumption of equal distribution over the whole firmament, we have again 5672 stars visible to highly acute unassisted vision" (MS. communication from Professor Argelander, March 1850).

([171]) p. 90.—Of stars down to the 6th magnitude, Schubert reckoned the number for the whole heavens at 7000,—almost the same as the number assumed by me in the first volume of Cosmos (English edition, p. 140), and for the horizon of Paris above 5000; and down to the 9th magnitude inclusive for the whole sphere, 70000 (Astronomie, Th. iii. S. 54). All these numbers are considerably too high. Argelander finds, from the 1st to the 8th magnitude, only 58000.

([172]) p. 90.—"Patrocinatur vastitas cœli, immensa discreta altitudine, in duo atque septuaginta signa. Hæc sunt rerum et animantium effigies, in

quas digessere cœlum periti. In his quidem mille sexcentas adnotavere stellas, insignes videlicet effectu visuve." . . . (Plin. ii. 41.) "Hipparchus nunquam satis laudatus, ut quo nemo magis approbaverit cognationem cum homine siderum animasque nostras partem esse cœli, novam stellam et aliam in ævo suo genitam deprehendit, ejusque motu, qua die fulsit, ad dubitationem est adductus, anne hoc sæpius fieret moverenturque et eæ quas putamus affixas; itemque ausus rem etiam Deo improbam, adnumerare posteris stellas ac sidera ad nomen expungere, organis excogitatis, per quæ singularum loca atque magnitudines signaret, ut facile discerni posset ex eo, non modo an obirent nascerenturve, sed an omnino aliqua transirent moverenturve, item an crescerent minuerenturque, cœlo in hereditate cunctis relicto, si quisquam qui cretionem eam caperet inventus esset" (Plin. ii. 26).

([173]) p. 91.—Delambre, Hist. de l'Astr. anc. T. i. p. 290; and Hist. de l'Astr. mod. T. ii. p. 186.

([174]) p. 91.—Outlines, § 831; Edouard Biot sur les Etoiles Extraordinaires observées en Chine, in the Connaissance des Temps pour 1846.

([175]) p. 91.—It is to Aratus that the Apostle Paul refers with implied praise in his discourse at Athens (Acts, ch. xvii., v. 28). The name is not, indeed, mentioned, but it is impossible to mistake the allusion to a passage from Aratus (Phæn. v. 5) on the community of mortals with the Deity. Aratus is also singularly enough referred to at a not very different date by Ovid (Amor. i. 15).

([176]) p. 92.—Ideler, Untersuchungen über den Ursprung der Sternnamen, S. 30—35. Baily, in the Mem. of the Astron. Soc., Vol. xiii. 1843, pp. 12 and 15, also treats of the dates according to the Christian era, with which we should connect the observations of Aristyllus, as well as the Star-tables of Hipparchus (128, not 140, B.C.), and of Ptolemy A.D. 138.

([177]) p. 92.—Compare Delambre, Hist. de l'Astr. anc. T. i. p. 184; T. ii. p. 260. The statement, that although Hipparchus always designates the stars by their Right Ascension and Declination, yet that his Star-catalogue, like that of Ptolemy, was arranged according to longitude and latitude, appears to have little probability in its favour; and is in contradiction to the Almagest, book vii. cap. 4, where the relations to the Ecliptic are spoken of as something novel, tending to facilitate the knowledge of the movement of the fixed stars round the pole of the Ecliptic. The Star-table with appended longitudes, discovered by Petrus Victorius in a Medicean codex, and published with the life of Aratus, at Florence, in 1567, is indeed attributed by him to Hipparchus but without proof. It appears to be a mere transcript of Ptolemy's Table,

from an old manuscript of the Almagest, omitting all the latitudes. As Ptolemy was but imperfectly acquainted with the amount of the retrogression of the equinoctial and solstitial points, (Almag. vii. c. 2, p. 13, Halma), and had assumed it about 0·28 too slow, his table (Ideler, in the work above cited, p. 34), which he intended to correspond to the beginning of the reign of Antoninus, gives the places of the stars for a much earlier epoch (*i. e.* for the year A.D. 63). Compare also considerations and tables for facilitating the reduction of modern star places to the time of Hipparchus, given by Encke in Schumacher's Astr. Nachr., No. 608, S. 113 to 126. The earlier epoch for which, unknown to its author, Ptolemy's table represents the firmament, coincides very probably with the epoch to which we may refer the Catasterisms of the Pseudo-Eratosthenes, which, as I have already remarked elsewhere, are later than the Augustean Hyginus, appear to be taken from him, and are unconnected with the poem of Hermes by the true Eratosthenes. (Eratosthenica, composuit God. Bernhardy, 1822, p. 114, 116, and 129.) These Catasterisms of the Pseudo-Eratosthenes contain barely 700 separate stars distributed among the mythical constellations.

(178) p. 93.—Kosmos, Bd. ii. S. 260 and 433; English edition, p. 224, and lxix. note 354. The Paris Library possesses a manuscript of the Ilkhanian Tables, written by the hand of the son of Nassir-Eddin. They take their name from the title Ilkhan, assumed by the Tartar princes who reigned in Persia. Reinaud Introd. de la Géogr. d'Aboulféda, 1848, p. 139.

(179) p. 93.—Sédillot fils, Prolégomènes des Tables Astr. d'Olong-Beg, 1847, p. 134; Note 2; Delambre, Hist. de l'Astr. du moyen âge, p. 8.

(180) p. 93.—In my examinations into the relative value of astronomical determinations of geographical positions in the interior of Asia, (Asie Centrale, T. iii. p. 581—596), I have given the latitudes of Samarcand and Bokhara according to the different Arabian and Persian manuscripts in the Paris Library. I have shewn that the latitude of Samarcand is probably above 39° 52′, while the greater number and best MSS. of Ulugh Beig have 39° 37′, and the Kitab al-athual of Alfares, and the Kanun of Albyruni, 40°. I think it right again to call attention to the importance to geography and to the history of astronomy, of a new and trustworthy determination of the latitude and longitude of Samarcand. We know the latitude of Bokhara by culminations of stars from Burnes' Travels; they make it 39° 43′ 41″. This would give the errors of the two fine Persian and Arabian MSS. (Nos. 164 and 2460) in the Paris Library at only 7 to 8 minutes; but Major Rennell, generally so happy in his combinations, would have been in error 19′ for the latitude of Bokhara.

(Humboldt, Asie Centrale, T. iii. p. 592; and Sédillot in the Prolégomènes d'Oloug-Beg, p. 123—125.)

([181]) p. 94.—Kosmos, Bd. ii. S. 327—332, and 485 Anm. 5—8; English edition, p. 287—292, and notes 446—448; Humboldt, Examen Critique de l'Histoire de la Géographie, T. iv. p. 321—336; T. v. p. 226—238.

([182]) p. 94.—Cardani Paralipomenon, lib. viii. cap. 10; (Opp. T. ix. ed. Lugd. 1663, p. 508).

([183]) p. 95.—Kosmos, Bd. i. S. 90—93: Eng. edition, p. 78—80.

([184]) p. 96.—Baily, Catalogue of those Stars in the Histoire Céleste of Jérôme De Lalande, for which tables of reduction to the epoch 1800 have been published by Prof. Schumacher, 1847, p. 1195. On the benefits of complete Star-catalogues, see the remarks of Sir John Herschel, Cat. of the British Assoc., 1845, p. 4, S. 10. Compare also, respecting Missing Stars, Schumacher, Astr. Nachr., No. 624, and Bode's Jahrb. for 1817, S. 249.

([185]) p. 97.—Memoirs of the Royal Astron. Soc., Vol. xiii. 1843, pp. 33 and 168.

([186]) p. 97.—Bessel, Fundamenta Astronomiæ pro anno 1755, deducta ex observationibus viri incomparabilis James Bradley in Specula astronomica Grenovicensi, 1818. (Compare also Bessel, Tabulæ Regiomontanæ reductionum observationum astronomicarum ab anno 1750 usque ad annum 1850 computatæ, 1830.)

([187]) p. 97.—I compress into a note a brief list of Star-Catalogues containing lesser masses, or a smaller number of positions, adding the name of the observer, and the number of the determinations of place. Lacaille (who observed for barely ten months in 1751 and 1752, and with a magnifying power of only eight times), 9766 southern stars to the 7th magnitude inclusive, reduced to the year 1750 by Henderson; Tobias Mayer, 998 stars for 1756; Flamsteed, originally 2866, but augmented by Baily's care by 564 additional (Mem. of the Astr. Soc. Vol. iv. p. 129—164); Bradley, 3222, reduced by Bessel to the year 1755; Pond, 1112; Piazzi, 7646 stars for 1800; Groombridge, 4243, mostly circumpolar stars, for 1810; Brisbane and Rümker, 7385 southern stars, observed in New Holland in the years 1822—1828; Airy, 2156 stars, reduced to the year 1845; Rümker, 12,000, on the Hamburg horizon; Argelander (Cat. of Abo), 560; Taylor (Madras), 11015. The British Association Catalogue, 1845, reduced under Mr. Baily's superintendence, contains 8377 stars, from the 1st magnitude to the 7½. For the most southern stars, we have besides, the rich registers of Henderson, Fallows, Maclear, and Johnson at St. Helena.

(188) p. 98.—Weisse, Positiones mediæ stellarum fixarum in Zonis Regiomontanis a Besselio inter—15° et + 15° decl. observatarum ad annum 1825, reductæ (1846); with an important Preface by Struve.

(189) p. 99.—Encke, Gedächtniss rede auf Bessel, S. 13.

(190) p. 99.—Compare Struve, Etudes d'Astr. stellaire, 1847, p. 66 and 72; Kosmos, Bd. i. S. 156 (English edition, p. 140); and Mädler Astr. 4th Aufl. S. 417.

(191) p. 102.—Kosmos, Bd. ii. S. 197 and 432, Anm. 11 (English edition, p. 163, and note 251).

(192) p. 102.—Ideler, Unters. über die Sternnamen, S. xi. 47, 139, 144, and 243; Letronne sur l'Origine du Zodiaque grec 1840, p. 25.

(193) p. 103.—Letronne, id. p. 25, and Carteron, Analyse des Recherches de M. Letronne sur les Représentations Zodiacales, 1843, p. 119; "Il est très douteux qu'Eudoxe (Ol. 103) ait jamais employé le mot ζωδιακός. On le trouve pour la première fois dans Euclide et dans le Commentaire d'Hipparque sur Aratus (Ol. 160). Le nom d'écliptique ἐκλειπτικός est aussi fort récent." (Compare Martin in the Commentary to Theonis Smyrnæi Platonici Liber de Astronomia, 1849, p. 50 and 60.)

(194) p. 103.—Letronne, Orig. du Zod. p. 25, and Analyse crit. des Représ. Zod. 1846, p. 15. Ideler and Lepsius also consider it probable that "the knowledge of the Chaldean zodiac, both as respects the division and the name, had reached the Greeks as early as the 7th century before our era, but that the reception of the several zodiacal figures into the Grecian astronomical literature was later, and only followed gradually" (Lepsius, Chronologie der Ægypter, 1849, S. 65 and 124). Ideler is inclined to believe that the Orientals had for their twelve divisions (Dodecatomery) names, but without figures; Lepsius thinks it natural to suppose "that the Greeks, at a time when their sphere was in great part unoccupied, would add to their own the Chaldean constellations from which the twelve divisions were named." But, on this supposition, might we not ask why the Greeks should have had at first only eleven signs, and not all the twelve signs of the Chaldean Dodecatomery? If they had received twelve figures, they would surely not have cut out one to replace it subsequently.

(195) p. 104.—On the passage referred to in the text, and interpolated by a transcriber as if belonging to Hipparchus, see Letronne, Orig. du Zod. 1840, p. 20. As early as 1812, when I was myself still inclined to suppose that the Greeks had been very early acquainted with the sign of the Balance, I pointed out, in a carefully written memoir on the passages from Greek and

Roman Antiquity, in which the name of the Balance as a zodiacal sign occurs, the passage of Hipparchus (Comment. in Aratum, lib. iii. cap. 2), in which there is mention of the θηρίον which holds the Centaur (by his fore-foot), as well as the remarkable passage of Ptolemy, lib. ix. cap. 7 (Halma, T. ii. p. 170). In this latter passage the southern Balance is named, with the addition *κατὰ Χαλδαίους*, and is opposed to the Pincers (Scheeren) of the Scorpion, in an observation certainly not made in Babylon, but by the astrological Chaldeans scattered in Syria and Alexandria (Vues des Cordillères et Monumens des peuples indigènes de l'Amérique, T. ii. p. 380). Buttmann was disposed to think, but which seems little probable, that the χηλαι had originally signified the two scales of the Balance, and were afterwards by a misunderstanding converted into the pincers of a scorpion. (Compare Ideler "Untersuchungen über die astronomischen Beobachtungen der Alten," S. 374, and the same writer, "über die Sternnamen," S. 174—177, with Carteron, "Recherches de M. Letronne," p. 113). In the analogy between many names of the twenty-seven "houses of the moon," and the Dodecatomery of the zodiac, it has always appeared to me remarkable that we find the sign of the Balance among the certainly very ancient Indian Nakschatras (moon-houses). (Vues des Cordillères, T. ii. p. 6—12.)

([196]) p. 104.—Compare A. W. von Schlegel über Sternbilder des Thierkreises im alten Indien, in der Zeitschrift für die Kunde des Morgenlandes, Bd. i. Heft 3, 1837, and his Commentatio de Zodiaci antiquitate et origine, 1839, with Adolph Holtzmann über den griechischen Ursprung des indischen Thierkreises, 1841, S. 9, 16, and 23. In the last-named work, it is said:—The passages adduced from the Amarakoscha and the Ramayana are not of doubtful interpretation—they speak in the clearest terms of the zodiacal circle itself; but if the works which contain them were composed before the knowledge of the Greek Zodiac could have reached India, it ought to be closely examined whether those passages are not more recent interpolations."

([197]) p. 105—Compare Buttmann in the Berlin Astron. Jahrbuch for 1822, S. 93; Olbers, on the more modern constellations, in Schumacher's Jahrbuch for 1840, S. 238—251, and Sir John Herschel, Revision and Rearrangement of the Constellations with special reference to those of the Southern Hemisphere, in the Memoirs of the Astr. Soc., Vol. xii. p. 201—224 (with a very exact distribution of the Southern Stars of the 1st to 4th magnitudes). On the occasion of the formal discussion between Lalande and Bode, respecting the introduction of Lalande's house-cat and of a harvest-man (Messier!), Olbers complains, that in order to make room for new

figures, "Andromeda must lay her arm in another place than that which it has occupied for 3000 years."

([198]) p. 105.—Kosmos, Bd. iii. S. 37 and 53 (English edition, p. 28 and note 52).

([199]) p. 105.—According to Democritus and his scholar Metrodorus, Stob Eclog. phys. p. 582.

([200]) p. 106.—Plut. de Plac. Phil. ii. 11; Diog. Laert. viii. 77; Achilles. Tat. ad Arat. cap. 5; Εμπ, *κρυσταλλώδη τοῦτον (τὸν οὐρανὸν) εἶναί φησιν, ἐκ τοῦ παγετώδους συλλεγέντα*; so also we find only the expression crystal-like or crystalline in Diog. Laert. viii. 77, and Galenus, Hist. phil. 12 (Sturz, Empedocles Agrigent, T. i. p. 321). Lactantius de opificio Dei, c. 17: an si mihi quispiam dixerit *æneum* esse cœlum, aut *vitreum*, aut, ut Empedocles ait, ærem *glaciatum*, statimne assentiar, quia cœlum ex qua materia sit ignorem? Respecting this cœlum vitreum, we have no earlier Hellenic evidence; for only one celestial body, the Sun, is termed by Philolaos a glass-like or vitreous body, which receives and throws back to us the rays from the central fire. The view of Empedocles, referred to in the text, of the reflection of the solar light from the Moon, speaking of the latter as a body which had consolidated in the manner of hail stones, is mentioned by Plutarch, apud Euseb. Praep. Evangel. i. p. 21, D, and de facie in orbe Lunæ, cap. 5. When in Homer and Pindar the epithets *χάλκεος* and *σιδήρεος* are applied to Uranos, it is only in a figurative sense, like hearts of brass, voice of brass, as signifying stedfast, enduring, imperishable (Völcker über Homerische Geographie, 1830, S. 5). The word *κρύσταλλος* applied to the ice-like, transparent substance of rock-crystal, first occurs before Pliny, in Dyonisius Periegetes, 781, Ælian, xv. 8, and in Strabo, xv. p. 717, Casaub. The supposition that the idea of the crystal heavens, as a vault of ice (äer glaciatus of Lactantius), had arisen among the ancients, from observing, when travelling among mountains, the increasing cold in ascending, and from the sight of snow-capped mountains, is refuted by our knowing that they imagined a fiery ether to exist at the limit of our atmosphere (Aristot. Meteorol. i. 3; de Cælo, ii. 7, p. 289). In speaking of the music of the spheres, which, "according to the Pythagoreans, is unheard by men because it never ceases, and sounds are only heard if interrupted by silence," Aristotle (de Cœlo, ii. p. 290) affirms, singularly enough, that the motion of the spheres produces heat in the air below, but without heating themselves. Their vibrations produce heat, not sound. "The motion of the sphere of the fixed stars is the most rapid (Aristot. de Cælc, ii. 10, p. 291); and while this sphere and the

bodies attached to it revolve around, the space nearest thereto is continually heated by this movement, and thus there is produced a warmth which extends down to the surface of the earth" (Meteorol. i. 3, p. 340). I have always been struck by the circumstance that Aristotle avoids the term "crystal heaven," although the expression affixed to stars, *ἐνδεδεμένα ἄστρα*, seems to indicate the general idea of solid spheres, but without specifying the kind of material. Cicero is not very intelligible on this point, but in his commentator (Macrobius in Cic. Somnium Scipionis, i. c. 20, p. 99, ed. Bip.) we find traces of freer ideas respecting the decrease of heat in increasing height. According to him, the extreme zones of the heavens are subject to perpetual cold. "Ita enim non solum terram sed ipsum quoque cœlum, quod vere mundus vocatur, temperari a sole certissimum est, ut extremitates ejus, quæ a via solis longissime recesserunt, omni careant beneficio caloris et una frigoris perpetuitate torpescant." These "extremitates cœli," in which the Bishop of Hippo (Augustinus, ed. Antv. 1700, i. p. 102, and iii. p. 99) placed, as in a region of ice-cold water, the uppermost and therefore the coldest of all planets, Saturn, still belong to the atmosphere, for it is only still higher above this extreme limit that, according to an earlier statement of Macrobius (i. c. 19, p. 93), is placed the fiery æther, which, strangely enough, does not prevent that eternal cold. "Stellæ supra cœlum locatæ, in ipso purissimo æthere sunt, in quo omne, quidquid est, lux naturalis et sua est (the seat of self-luminous heavenly bodies), quæ tota cum igne suo ita sphæræ solis incumbit, ut cœli zonæ, quæ procul a sole sunt, perpetuo frigore oppressæ sint." If I enter into so much detail respecting the connection of ideas in meteorology and physics entertained by the Greeks and Romans, it is only because, excepting in the works of Ukert, Henri Martin, and the excellent fragment of Meteorologia Veterum by Julius Ideler, these subjects have hitherto been treated only in a very incomplete, and, most often, superficial manner.

([201]) p. 106.—That fire had the power of rigidifying (Aristot. Probl. xiv. 11), and that the formation of ice itself is promoted by heat, were deeply-rooted opinions in the Physics of the Ancients, resting on a fanciful antithetical theory (Antiperistasis), or obscure ideas of polarity (a calling forth of opposite qualities or states); Kosmos, Bd. iii. S. 15 and 29 (English edition, p. 15 and note 22). Hail, it is said, is formed in larger masses when the atmospheric strata are warmer (Aristot. Meteor. i. 12). In winter fishing on the shores of the Euxine, hot water was used to increase the formation of ice, in

the vicinity of an upright tube (Alex. Aphrodis. fol. 86, and Plut. de Primo Frigido, c. 12).

(202) p. 107.—Kepler says expressly, in Stella Martis, fol. 9, "Solidos orbes rejeci; and in Stella Nova, 1606, cap. 2, p. 8, "planetæ in puro æthere, perinde atque aves in aere, cursus suos conficiunt." (Compare also p. 122.) Earlier, however, his opinion had been inclined in favour of a solid icy celestial vault (orbis ex aqua factus gelu concreta propter solis absentiam). Kepler, Epit. Astr. Copern. i. 2, p. 51. Two thousand years before Kepler, Empedocles said that the fixed stars were fastened to the crystal heaven, but that the planets were free and unrestrained (*τοὺς δὲ πλανήτας ἀνεῖσθαι*). (Plut. Plac. Phil. ii. 13; Emped. i. p. 335, Sturz; Euseb. Praep. Evang. xv. 30, Col. 1688, p. 839.) It is difficult to conceive in what manner the fixed stars were imagined to be attached to solid spheres, and yet to revolve singly, as supposed by Plato in the Timæus (Tim. p. 40, B), but not by Aristotle.

(203) p. 108.—Kosmos, Bd. ii. S. 352 and 506 (English edition, p. 312, and note 478).

(204) p. 108.—Kosmos, Bd. iii. S. 67 and 113 (English edition, p. 50, and note 105).

(205) p. 108.—"Les principales causes de la vue indistincte sont: aberration de sphéricité de l'œil, diffraction sur les bords de la pupille, communication d'irritabilité à des points voisins sur la rétine. La vue confuse est celle où le foyer ne tombe pas exactement sur la rétine, mais tombe ou devant ou derrière la rétine. Les queues des étoiles sont l'effet de la vision indistincte autant qu'elle depend de la constitution du cristallin. D'après un très ancien mémoire de Hassenfratz (1809), 'les queues au nombre de 4 ou 8 qu'offrent les étoiles ou une bougie vue à 25 mètres de distance, sont les caustiques du cristallin formées par l'intersection des rayons refractés.' Ces caustiques se meuvent à mesure que nous inclinons la tête. La propriété de la lunette de terminer l'image fait qu'elle concentre dans un petit espace la lumière qui sans cela en aurait occupé un plus grand. Cela est vrai pour les étoiles fixes et pour les disques des planètes. La lumière des étoiles qui n'ont pas de disques réels, conserve la même intensité quelque soit le grossissement. Le fond de l'air duquel se détache l'étoile dans la lunette, devient plus noir par le grossissement qui dilate les molécules de l'air qu'embrasse le champ de la lunette. Les planètes à vrais disques deviennent elles-mêmes plus pâles par cet effet de dilatation.—Quand la peinture focale est nette, quand les rayons partis *d'un point* de l'objet se sont concentrés en *un seul point* dans l'image, l'oculaire donne des résultants satisfaisants. Si au contraire les rayons

émanés d'un point ne se réunissent pas au foyer en un seul point, s'ils y forment *un petit cercle*, les images de deux points contigus de l'objet empiètent nécessairement l'une sur l'autre; leurs rayons se confondent. Cette confusion la lentille oculaire ne saurait la faire disparaître. L'office qu'elle remplit exclusivement, c'est de grossir; elle grossit tout ce qui est dans l'image, les defauts comme le reste. Les étoiles n'ayant pas de diamètres angulaires sensibles, ceux qu'elles conservent toujours tiennent pour la plus grande partie au manque de perfection des instrumens (à la courbure moins regulière donnée aux deux faces de la lentille objective) et à quelques défauts et aberrations de notre œil. Plus une étoile semble petite, tout étant égal quant au diamètre de l'objectif, au grossissement employé et à l'éclat de l'étoile observée, et plus la lunette a de perfection. Or le meilleur moyen de juger si les étoiles sont très petites, si des points sont représentés au foyer par de simples points, c'est évidemment de viser à des étoiles excessivement rapprochées entr'elles et de voir si dans les étoiles doubles connues les images se confondent, si elles empiètent l'une sur l'autre, ou bien si on les aperçoit bien nettement séparées." Arago MSS. of 1834 and 1847.

(206) p. 108.—Hassenfratz sur les Rayons Divergens des Etoiles, in Delamétherie's Journal de Physique, T. lxix. 1809, p. 324.

(207) p. 109.—Horapollinis Niloi Hieroglyphica, ed. Conr. Leemans, 1835, cap. 13, p. 20. The learned editor, (Leemans) however, in opposition to Jomard, (Descr. de l'Egypte, T. vii. p. 423), remarks that neither on monuments nor rolls of papyrus has the figure of a star been found employed as a sign for the number 5 (Horap. p. 194).

(208) p. 109.—On board Spanish ships in the Pacific I found a persuasion prevailing among the sailors, that the moon's age could be determined, before her first quarter, by looking at her face through a piece of silk, and counting the number of images; a phenomenon of diffraction through narrow longitudinal apertures.

(209) p. 109.—Outlines, § 816. Arago made the diameter of the spurious disk of Aldebaran, shewn by a telescope, increase from 4″ to 15″ by diminishing the diameter of the object glass.

(210) p. 110.—Delambre, Hist. de l'Astr. Moderne, T. i. p. 193; Arago, Annuaire 1842, p. 366.

(211) p. 110.—" Minute and very close companions, the severest tests which can be applied to a telescope."—Outlines, § 837. Compare also Sir John Herschel, Cape Observations, p. 29, and Arago, in the Annuaire pour 1834, p. 302—305. Of bodies belonging to our solar system, we may employ, for

testing the power of light of a highly magnifying optical instrument, the 1st and 4th satellites of Uranus, seen again by Lassel and Otto Struve in 1847; the two innermost and the 7th satellites of Saturn, (Mimas, Enceladus, and Bond's Hyperion), and the satellite of Neptune, discovered by Lassel. The power of penetrating the depths of celestial space, afforded by telescopes, led Bacon, in an eloquent passage in praise of Galileo to whom he erroneously ascribed their invention, to compare them to ships which conduct men into an unknown ocean; "ut propriora exercere possint cum cœlestibus commercia." Works of Francis Bacon, 1740, Vol. i. Novum Organon, p. 361.

([212]) p. 111.—"The expression υπόκιῤῥος, which Ptolemy uniformly employs in his catalogue for the six stars named by him, indicates a slight degree of transition from fiery yellow to fiery red, thus, speaking precisely, it would signify a fiery reddish colour. To the other fixed stars, he seems to apply generally the epithet ξανθός, a fiery yellow. (Almag. viii. 3 ed.; Halma, T. ii. p. 94). Κιῤῥὸς is, according to Galen, (Meth. med. 12) a pale fire red, verging towards yellow. Gellius compares the word to melinus, which, according to Servius, means the same as gilvus and fulvus. As Sirius is called by Seneca (Nat. Quæst. i. 1) 'redder than Mars,' and as it is one of the stars called in the Almagest ὑπόκιῤῥοι, there remains no doubt that the word indicates the predominance, or at least the presence of a certain portion of red rays. The assertion that the epithet ποικίλος, applied to Sirius by Aratus, v. 327, is translated by Cicero, rutilus, is erroneous. Cicero says, indeed, v. 348—

Namque pedes subter rutilo cum lumine claret
Fervidus ille Canis stellarum luce refulgens;

but rutilo cum lumine is not a *translation* of ποικιλος, but an addition made by a free translator." (Extracts from letters to myself from Professor Franz.) Arago in the Annuaire for 1842, p. 351, says, "Si en substituant *rutilus* au terme grec d'Aratus, l'orateur romain renonce à dessein à la fidélité, il faut supposer que lui-même avait reconnu les propriétés rutilantes de la lumière de Sirius."

([213]) p. 111.—Cleom. Cycl. Theor. i. 11. p. 59.

([214]) p. 111.—Mädler, Astr. 1849, S. 391.

([215]) p. 111.—Sir John Herschel in the Edinb. Review, vol. lxxxvii. 1848, p. 189, and in Schum. Astr. Nachr. 1839, No. 372,—"It seems much more likely that in Sirius a red colour should be the effect of a medium interfered, than that in the short space of 2000 years, so vast a body should have actually undergone such a material change in its physical constitution. It may be

supposed the existence of some sort of *cosmical cloudiness*, subject to internal movements, depending on causes of which we are ignorant." (Compare Arago in the Annuaire pour 1842, p. 350—353.)

([216]) p. 112.—In Muhamedis Alfragani chronologica et astronomica elementa, ed. Jacobus Christmannus, 1590, cap. 22, p. 97, it is said,—"stella ruffa in Tauro Aldebaran; stella ruffa *in Geminis* quæ appellatur *Hajok*, hoc est Capra." But Alhajoc, Aijuk, are, in the Arabo-Latin Almagest, the usual names of Capella. Argelander also remarks justly that Ptolemy in the astrological work (Τετράβιβλος σίνταξις), vouched as genuine by style and ancient testimony, connects planets and stars according to similarity of colour, and thus joins together Capella and Martis stella, (quæ urit sicut congruit igneo ipsius colori,) with Aurigæ stella. (Compare Ptol. quadripart. construct. libri iv. Basil 1551, p. 383). Riccioli (Almagestum novum ed. 1650, T. i. Pars 1, lib. 6, cap. 2, p. 394) also reckons Capella, with Antares, Aldebaran, and Arcturus, among the red stars.

([217]) p. 113.—See Chronologie der Ægypter, by Richard Lepsius, Bd. i. 1849, S. 190—195, and 213. The complete construction of the Egyptian calender is placed in the earliest part of the year 3285 before the Christian era—*i. e.* about a century and a half before the building of the great pyramid of Cheops-Chufu, and 940 years before the epoch usually assigned to the Deluge. (Compare Kosmos, Bd. ii. S. 402, English edition, p. xxvii., Note 146). In the calculations which have been made in reference to the circumstance, that the inclination of the narrow subterranean passage leading into the interior of the pyramid, measured by Colonel Vyse, corresponds very nearly to the angle 26° 15′, which, in the time of Cheops-Chufu, the star $\alpha$ Draconis which marked the pole attained at its inferior culmination at Gizeh,—the epoch of the building of the pyramid is taken, not at 3430 B.C., as given in Kosmos from Lepsius, but at 3970 B.C. as in the Outlines of Astr. § 319. This difference of 540 years is the less opposed to the assumption of $\alpha$ Draconis having been the pole-star, as in 3970 its polar distance was still 3° 44′.

([218]) p. 113.—I have taken what follows from letters of Professor Lepsius to myself (February 1850):—"The Egyptian name of Sirius, marked as a female star, is Sothis; hence, in Greek, ἡ Σῶθις is identified with the goddess Sote (oftener Sit in hieroglyphics), and in the temple of the great Ramses at Thebes with Isis-Sothis. (Lepsius, Chronol. der Ægypter, Bd. i. S. 119 and 136). The signification of the root is found in Coptic, and allied with a numerous family of words, the different members of which, though apparently

departing widely from each other, may, however, be arranged as follows:—By a threefold transference of the verbal signification, we obtain from the original meaning—to project, projicere (sagittam, telum)—1st, seminare, to sow; then extendere, to extend or stretch (as spun threads); and lastly, what is here most important, 'to radiate light,' 'to shine' (as do stars and fire). The names of the divinities—Satis (the archer, *female*), Sothis (the radiant, *female*), and Seth (the fiery, *male*), may be connected with this series of ideas. There may be pointed out hieroglyphically—sit or seti, the arrow or dart, as well as the ray; seta, to spin; setu, scattered grains. Sothis is especially the *bright-beaming* star, regulating seasons and periods. The small triangle, always painted yellow, which is a symbolical sign of Sothis, is employed in the designation of the *radiant sun*, being placed in triple rows, the triangles always pointing downwards from the sun. Seth is the fire-god, the burning or scorching; in opposition to the warming and fertilizing waters of the inundation of the Nile—the female divinity Satis. She is the goddess of the Cataracts, because the swelling of the Nile began with the appearance of the star Sothis, at the time of the summer solstice. In Vettius Valens, the star itself is called Σηϑ instead of Sothis; but we cannot by any means, as Ideler has done (Handbuch der Chronologie, Bd. i. S. 126), identify Thoth with Seth or Sothis, either as to name or person." (Lepsius, Bd. i. S. 136.)

To these considerations, taken from the earliest Egyptian antiquity, I subjoin some Greek, Zend, and Sanscrit etymologies. "Σείρ, the sun," says Professor Franz, "is an ancient radical, differing only in pronunciation from ϑερ, ϑέρος, heat, summer, where the sound of the vowel is altered, as in τεῖρος and τέρος, or τέρας. The correctness of the assigned relations between the radicals σεὶρ, and ϑερ, ϑέρος, is confirmed, not only by the application of ϑερείτατος in Aratus, v. 149 (Ideler, Sternnamen, S. 241), but also by the later use of the forms derived from σεὶρ, σειρὸς, σεὶριος, σειρινός, hot, burning. It deserves remark that σειρὰ, or σειρινὰ ἱμάτια, is pronounced quite like ϑερινὰ ἱμάτια, light summer clothing. But the peculiar form σείριος is of wider application, it is the epithet given to all the heavenly bodies which influence the heat of summer: thus, according to the poet Archilochus, the Sun was called σείριος ἀστὴρ; and Ibycus calls the heavenly bodies σείρια, 'the shining.' That it is really the sun which is meant in the words of Archilochus, πολλοὺς μὲν αὐτοῦ σείριος καταναυεῖ ὀξὺς ἐλλάμπων, cannot be doubted. It is true that, according to Hesychius and Suidas, Σείριος signifies both the Sun and the dog-star; but I am as certain as is the new editor of Theon of Smyrna,

M. Martin, that the passage of Hesiod (Opera et Dies, v. 417) refers, as Tzetzes and Proclus make it do, to the Sun, and not to the dog-star. The verb σειριᾶν, which may be translated 'to sparkle,' comes from the adjective σείριος, which has established itself as the epitheton perpetuum of the dog-star. Aratus, v. 331, says of Sirius, ὀξέα σειριάει, 'it sparkles strongly.' When standing alone, the word Σειρήν, the Siren, has quite a different etymology; and your conjecture, that it is only a case of accidental similarity of sound to the bright star Sirius, is perfectly well founded. They are quite in error who, according to Theon Smyrnæus (Liber de Astronomia, 1850, p. 202), would derive Σειρὴν from σειριάζειν (a, moreover, quite unaccredited form for σειριᾶν). While the motion of heat and light are expressed in σείριος, the word Σειρὴν has a root which represents the flowing tone of the natural phenomenon. It seems to me probable that Σειρὴν is connected with εἴρειν; (Plato, Cratyl. 398 D. τὸ γὰρ εἴρειν λέγειν ἐστί;) the originally sharp aspiration passing into the hissing sound." Extracted from letters to myself from Prof. Franz, January 1850.

According to Bopp, "the Greek Σειρ, the Sun, can be easily connected by intermediate links with the Sanscrit word 'svar,' which indeed does not signify the Sun, but the Heavens (as something bright or shining). The usual Sanscrit name for the Sun is 'sûrya,' a contraction of 'svarya.' The root 'svar,' signifies in general, to shine. The Zend name for the Sun is 'hvare,' with *h* instead of *s*. The Greek θερ, θέρος, and θερμὸς, comes from the Sanscrit word, gharma (Nom. gharmas), warmth, heat."

The acute Max. Muller, who has edited the Rigveda, remarks "that the Indian astronomical name for the dog-star, Lubdhaka, which signifies 'hunter,' regarded in connection with the neighbouring constellation of Orion, seems to point to a highly ancient Aric community of view in the contemplation of this group of stars." He is most inclined to derive Σείριος from the Vedic word "sira" (whence the adjective sairya), and the root "sri," to go, to walk; so that the Sun and the brightest of stars, Sirius, would have had the term moving or wandering star as their original name. (Compare also Pott. Etymologische Forschungen, 1833, S. 130.)

([219]) p. 113.—Struve, Stellarum compositarum Mensuræ micrometricæ, 1837, p lxxiv. and lxxxiii.

([220]) p. 114.—Sir John Herschel, Cape Observations, p. 34.

([221]) p. 114.—Mädler, Astronomie, S. 436.

([222]) p. 114.—Kosmos, Bd. ii. S. 367 and 513, Anm. 63, English edition, p. 327, and Note 503.

(223) p. 114.—Arago, Annuaire pour 1842, p. 348.

(224) p. 114.—Struve, Stellæ comp. p. lxxxii.

(225) p. 115.—Sir John Herschel, Cape Observations, pp. 17 and 102 (Nebulæ and Clusters, No. 3435).

(226) p. 115.—Humboldt, Vues des Cordillères et monumens des peuples indigènes de l'Amérique, T. ii. p. 55.

(227) p. 115.—Julii Firmici Materni Astron. libri viii. Basil, 1551, lib. vi. cap. 1, p. 150.

(228) p. 115.—Lepsius, Chronol. der Ægypter, Bd. i. S. 143. "In the Hebrew text they are called Asch, the Giant (Orion?), the 'many stars,' (the Pleiades, Gemut?), and the Chambers of the South. The Septuagint version is: ὁ ποιῶν Πλειάδα καὶ 'Εσπερον καὶ 'Αρκτοῦρον καὶ ταμεῖα νότου."

(229) p. 116.—Ideler, Sternnamen, S. 295.

(230) p. 116.—Martianus Capella changes Ptolemæon into Ptolemæus. Both names were given by the flatterers at the Egyptian Court. Amerigo Vespucci believed he had seen three Canopuses, one of which was quite dark (fosco), Canopus ingens et niger in the Latin translation: no doubt one of the black coal sacks (Humboldt, Examen crit. de la Géogr. T. v. p. 227—229). In the Elem. Chronol. et Astron. of El-Fergani (p. 100), it is related that the Christian pilgrims were wont to call the Sohel of the Arabs (Canopus), the Star of St. Catherine, because they were accustomed to welcome and admire it as their guiding star in journeying from Gaza to Mount Sinai. In a fine episode in the oldest heroic poem of Indian antiquity, the Ramayana, the stars near the southern pole are declared to be more recently created than the more northern ones for a singular reason. When the Brahminic Indians,—entering the lands of the Ganges from the north-west, advanced from 30° N. latitude farther into the tropics, subjecting the aborigines,—as they approached Ceylon they saw stars before unknown rise above the horizon. According to ancient custom, they combined these stars into new constellations. By a bold fiction, the later-seen stars were said to have been created later by the wonder-working power of Visvamitra, who "threatened the old gods, that, with his more richly-starred southern hemisphere, he would overpower the northern one" (A. W. von Schlegel, in the Zeitschrift für die Kunde des Morgenlandes, Bd. i. S. 240). This Indian myth, expressive of the astonishment of wandering nations at the aspect of regions of space before unseen (as the celebrated Spanish poet, Garcilaso de la Vega, said of those who travel, "they change at once their country and their stars," "mudan de

pays y de estrellas"), reminds us vividly of the impression which must have been made even on the rudest nations, when at the same part of the Earth's surface they first saw rise above the horizon large stars such as those in the feet of the Centaur, the Southern Cross, Eridanus, and the constellation of the Ship, whilst others before familiar disappeared. By the precession of the equinoxes, fixed stars approach and again recede from our view. I have already remarked, in another place, that 2900 years before our Era,—at a time, therefore, when the great pyramid had already stood five hundred years,—the constellation of the Southern Cross was 7° above the horizon of the countries bordering on the Baltic Sea. (Compare Kosmos, Bd. i. S. 155, and Bd. ii. S. 333. Eng. ed. Vol. i., p. 139. Vol. ii. p. 293). " Canopus, on the other hand, can never have been visible in the locality of Berlin; its distance from the South Pole of the Ecliptic is only 14°, and it would have required that the distance should have been 1° greater for the star to have ever reached the limit of visibility in our horizon."

([231]) p. 116.—Kosmos, Bd. ii. S. 203 (English edition, p. 169—170).

([232]) p. 116.—Olbers in Schumacher's Jahrb. für 1840, S. 249; and Kosmos, Bd. iii. S. 151.

([233]) p. 117.—Etudes d'Astr. stellaire, Note 74, p. 31.

([234]) p. 117.—Outlines of Astr. § 785.

([235]) p. 118.—Id. § 795 and 796; Struve, Etudes d'Astr. stellaire, p. 66—73 (also Note 75).

([236]) p. 118.—Struve, p. 59. Schwink finds in his maps, R. A. 0°—90°, 2858 stars; R. A. 90°—180°, 3011 stars; R. A. 180°—270°, 2688 stars; R. A. 270°—360°, 3591 stars; total 12,148 stars down to the 7th magnitude.

([237]) p. 119.—On the circular nebula in the right hand of Perseus (near the sword handle), see Eratosth. Catast. c. 22, p. 51, Schaubach.

([238]) p. 119.—Sir John Herschel's Cape Observations, § 105, p. 136.

([239]) p. 119.—Outlines, § 864—869, p. 591—596; Mädler, Astr. S. 764.

([240]) p. 120.—Cape Observations, § 29, p. 19.

([241]) p. 122.—Sir John Herschel says:—"A stupendous object, a most magnificent *globular* cluster *completely insulated*, upon a ground of the sky perfectly *black* throughout the whole breadth of the sweep." (Cape, p. 18 and 51, Pl. iii. fig. 1; Outlines, § 895, p. 615.

([242]) p. 122.—Bond, in the Memoirs of the American Academy of Arts and Sciences, new series, Vol. iii. p. 75.

([243]) p. 123.—Outlines, § 874, p. 601.

([244]) p. 123.—Delambre, Hist. de l'Astr. Moderne, T. i. p. 697.

([245]) p. 124.—We are indebted for the first and the only thoroughly complete description of the Milky Way in both hemispheres to Sir John Herschel, in his "Results of Astronomical Observations made during the years 1834—1838, at the Cape of Good Hope," § 316—335, and still more recently in his Outlines of Astronomy, § 787—799. I have followed him throughout the entire section of Kosmos which is devoted to the direction, branchings, and varied contents of the Milky Way. Compare also Struve, Etudes d'Astr. stellaire, p. 35—79; Mädler, Astr. 1849, § 213; Kosmos, Bd. i. S. 109 and 156 (English edition, pp. 96 and 140). I need scarcely remark here, that, in order not to mingle uncertainties with certainties, I have not introduced into the description of the Milky Way, what I observed and recorded respecting the very unequal light of the different parts of the gallactic zone during my long sojourn in the Southern Hemisphere, where the instruments with which I was provided commanded but little light.

([246]) p. 124.—The comparison of the Milky Way to a Celestial River caused the Arabs to give to parts of the constellation of Sagittarius, whose bow falls in a region full of stars, the name of "cattle going to drink," and even accompanying them by the ostrich, which requires so little water. (Ideler, Untersuchung über den Ursprung und die Bedeutung der Sternnamen, S. 78, 183, and 187; Niebuhr, Beschreibung von Arabien, S. 112.)

([247]) p. 124.—Outlines, p. 529; Schubert, Astr. Th. iii. S. 71.

([248]) p. 124.—Struve, Etudes d'Astr. stellaire, p. 41.

([249]) p. 125.—Kosmos, Bd. i. S. 156 and 415 Anm. 79 (English edition, p. 140, and Note 109).

([250]) p. 125.—"Stars standing on a clear black ground" (Cape Observations, p. 391). This remarkable belt (the Milky Way, when examined through powerful telescopes) is found (wonderful to relate!) *to consist entirely of stars scattered by millions*, like glittering dust on the *black ground* of the general heavens." Outlines, p. 182, 537, and 539.

([251]) p. 125.—"*Globular clusters*, except in one region of small extent (between 16h. 45m. and 19h. in R. A.) and *nebulæ of regular elliptic forms*, are comparatively rare in the Milky Way, and are found congregated in the greatest abundance in a part of the heavens the most remote possible from that circle." Outlines, p. 614. Huygens, as early as 1656, had had his attention drawn to the absence of nebulæ and nebulous patches in the Milky Way. In the same place in which he mentions the discovery and representation of the great nebula in the belt of Orion, by means of a 28-feet

refractor (1656), he said (as I have already remarked in the 2nd Vol. of Kosmos, S. 514, English edition, Note 503, p. cxviii): "viam lacteam perspicillis inspectam nullas habere nebulas"; and that the Milky Way, like all that had been taken for nebulous stars, was a great cluster of stars. The passage is printed in Hugenii Opera Varia, 1724, p. 593.

(252) p. 125.—Cape Observations, § 105, 107, and 328. On the annular nebula, No. 3686, see p. 114.

(253) p. 126.—"Intervals absolutely dark and *completely void of any star* of the smallest telescopic magnitude." Outlines, p. 536.

(254) p. 127.—"No region of the heavens is fuller of objects beautiful and remarkable in themselves, and rendered still more so by their mode of association, and by the peculiar features assumed by the Milky Way, which are without a parallel in any other part of its course" (Cape Observations, p. 386). This animated expression of Sir John Herschel's agrees perfectly with the impressions which I myself received. Captain Jacob (Bombay Engineers), in speaking of the intensity of light of the Milky Way in the vicinity of the Southern Cross, says, with striking truth,—"such is the general blaze of star-light near the Cross from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young moon." See Piazzi Smyth on the orbit of $\alpha$ Cent. in the Transactions of the Royal Society of Edinburgh (Vol. xvi. p. 445).

(255) p. 127.—Outlines § 789 and 791; Cape Observations, § 325.

(256) p. 127.—Almagest, lib. viii. cap. 2 (T. ii. p. 84 and 90, Halma) Ptolemy's description is in particular parts excellent, especially compared with Aristotle's treatment of the subject of the Milky Way. (Meteor. lib. 1. pp. 29 and 34, according to Ideler's Edition.)

(257) p. 129.—Outlines, p. 531. Also between $\alpha$ and $\gamma$ Cassiopeiæ, a strikingly dark spot or patch is ascribed to the contrast with the bright parts by which it is surrounded. See Struve, Etudes stell. Note 58.

(258) p. 130.—An extract from the exceedingly rare work of Thomas Wright of Durham (Theory of the Universe, London 1750), has been given by de Morgan in the Philosophical Magazine (Series iii. No. 32, p. 241). Thomas Wright, to whose writings the attention of astronomers has been permanently directed since the beginning of the present century, by the influence of the ingenious speculations of Kant and William Herschel on the form of our sidereal stratum, observed only with a reflector of 1 foot focal length.

([259]) p. 130.—Pfaff in W. Herschel's sämmtl. Schriften Bd. i. 1826, (S. 78—81; Struve, Etudes stell. p. 35—44).

([260]) p. 130.—Encke in Schumacher's Astr. Nachr. No. 622, (1847) S. 341—346.

([261]) p. 130.—Outlines, p. 536. On the next page it is said, on the same subject, "In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars of no great thickness compared with the distance which separates them from us."

([262]) p. 131.—Struve, Etudes stell. p. 63. Sometimes the largest telescopes reach a part of celestial space in which the existence of a remotely glimmering sidereal stratum is only indicated "by an uniform dotting or stippling of the field of view." See in the Cape Observations, p. 390, the section "on some indications of very remote telescopic branches of the Milky Way, or of an independent sidereal System, or Systems, bearing a resemblance to such branches."

([263]) p. 131.—Cape Observations, § 314.

([264]) p. 131.—Sir William Herschel in the Phil. Trans. for 1785, p. 21; Sir John Herschel, Cape Observations, § 293. (Compare also Struve, Descr. de l'Observatoire de Poulkova, 1845, p. 267—271).

([265]) p. 131.—"I think," says Sir John Herschel, "it is impossible to view this splendid zone from $\alpha$ Centauri to the Cross, without an impression, amounting almost to conviction, that the Milky Way is not a mere stratum, but annular; or, at least, that our system is placed within one of the poorer or almost vacant parts of its general mass, and that eccentrically, so as to be much nearer to the region about the Cross than to that diametrically opposite to it" (Mary Somerville on the Connection of the Physical Sciences, 1846, p. 419).

([266]) p. 131.—Cape Observations, § 315.

([267]) p. 136.—De admiranda Nova Stella anno 1572 exorta, in Tychonis Brahe Astronomiæ instauratæ Progymnasmata 1603, p. 298—304 and 578. I have followed in the text Tycho Brahe's own narrative. The unwarranted assertion, repeated in many books on Astronomy, that Tycho's attention was first called to the newly-appeared star by a concourse of country people has not, therefore, been noticed.

([268]) p. 136.—Cardanus, in his dispute with Tycho Brahe, went back to the star of the Magi, which he was disposed to identify with the star of 1572. Ideler, from his calculations of conjunctions of Saturn with Jupiter, and from

suppositions similar to those enounced by Kepler on the appearance of the new star in Ophiuchus in 1604, believed the star of the Wise Men, from the frequent confusion between αστὴρ and ἄστρον, to have been not a single great star, but a remarkable arrangement of stars, presented by the near approximation of two bright planets within less than a diameter of the moon from each other. (Compare Tychonis Progymnasmata, p. 324—330, with Ideler, Handbuch der Mathematischen und Technischen Chronologie. Bd. ii. (S. 399—407).

([269]) p. 136.—Progymn. p. 324—330. Tycho Brahe supports himself in his theory of the formation of new stars from the cosmical vapour, or nebulous matter of the Milky Way, on the remarkable passages of Aristotle, to which I have alluded in the 1st Vol. of Kosmos (Bd. i. S. 109 and 390, Note 18, Engl. ed. p. 96 and xviii. Note 48,) respecting the supposed relations subsisting between the tails of comets and the gaseous emanations from the nuclei of comets, and the Milky Way.

([270]) p. 140.—Other statements place the phenomenon in the year 388 or 398; Jacques Cassini, Élémens d'Astronomie, 1740 (Étoiles nouvelles), p. 59.

([271]) p. 148.—Arago Annuaire pour 1842, p. 332.

([272]) p. 149.—Kepler de Stella nova in pede Serp. p. 3.

([273]) p. 152.—On instances of stars which have not disappeared, see Argelander in Schumacher's Astronom. Nachr. No. 624, S. 371. To cite an example connected with antiquity, I will here recall how the carelessness of Aratus, in drawing up his poetic Catalogue of stars, has led to the often-renewed question, whether Vega (*α* Lyræ), may be either a new star or one which varies in long periods, since Aratus says that the constellation of the Lyre has only small stars. It may, indeed, seem surprising that Hipparchus does not notice this as an error in his Commentary; whilst yet he blames Aratus for his statements respecting the relative brightness of the stars in Cassiopeia, and in Ophiuchus. However, all this is merely accidental, and proves nothing; for, Aratus having ascribed to the constellation of the Swan only stars of middling brightness, Hipparchus (i. 14), in expressly contradicting this error, adds, that the bright star in the tail (Deneb) is but little inferior to the star in the Lyre (Vega). Ptolemy places Vega among the stars of the first order of magnitude; and in the Catasterisms of Eratosthenes (cap. 25), it is called λευκον καί λαμπρὸν. Seeing the many inaccuracies of a poet who was not himself an observer, would it be reasonable to found upon his statement the belief that *α* Lyræ (Pliny's Fidicula, xviii. 25) first

shone forth as a star of the 1st magnitude between the years 272 and 127 B.C., or between the time of Aratus and that of Hipparchus?

([274]) p. 155.—Compare Mädler, Astr. S. 438, Note 12, with Struve, Stellarum compos. Mensuræ microm. p. 97 and 98, star 2140. "I believe," says Argelander, "that it is very difficult to estimate correctly in a telescope of great power of light the brightness of such exceedingly different stars as are the two components of $\alpha$ Herculis. My experience is decidedly against the variability of the companion; for, in my numerous day observations with the telescopes of the Meridian circles at Abo, Helsingfors, and Bonn, I have never seen $\alpha$ Herculis single, which yet would have been the case, if the companion were only of the 7th magnitude when at its minimum. I believe it to be constant 5m. or 5·6m.

([275]) p. 155.—Mädler's Table (Astron. S. 435) contains 18 stars, having very different numerical elements. Sir John Herschel enumerates, including those alluded to in a note, above 45 (Outlines, § 819—826).

([276]) p. 156.—Argelander in Schumacher's Astr. Nachr. Bd. xxvi. (1848) No. 624, S. 369.

([277]) p. 158.—"If," says Argelander, "I take the least light of Algol, 1800, January 1, 18 h. 1 m., mean time at Paris, as my zero epoch, I obtain the following table:—

| Epoch. | Duration of Period. | | | Seconds. | Probable Errors. Seconds. |
|---|---|---|---|---|---|
| — 1987 | 2 days, | 20 hours, | 48 min. | 59.416 | ± 0·316 |
| — 1406 | ,, | ,, | ,, | 58·737 | 0·094 |
| — 825 | ,, | ,, | ,, | 58·393 | ± 0·175 |
| + 751 | ,, | ,, | ,, | 58·454 | ± 0·039 |
| + 2328 | ,, | ,, | ,, | 58·193 | ± 0·096 |
| + 3885 | ,, | ,, | ,, | 57·971 | ± 0·045 |
| + 5441 | ,, | ,, | ,, | 55·182 | ± 0·348 |

In this table the numbers signify as follows:—The epoch of the minimum, on the 1st of January 1800, being zero, the next preceding is — 1, the next following is + 1, &c.; the duration, or interval of time between the epochs — 1987 and — 1986, is exactly 2 d. 20 h. 48 m. 59.416 s.; whilst that between + 5441 and + 5442 is 2 d. 20 h. 48 m. 55.182 s.; the first corresponding to the year 1784, the last to the year 1842. The final column, with the ± sign, contains the probable errors. That the decrease is becoming more and more rapid is shewn by the last number, as well as by my observations since 1847.

([278]) p. 158.—Argelander's formula for representing all the observed maxima of Mira Ceti, as communicated to me by himself, is the following:—

$$1751,\ \text{Sept. } 9,76 + \overset{\text{days}}{331.3363} + \overset{\text{d.}}{10.5}\ \text{Sin.}\left(\frac{360^\circ}{11}E + 86^\circ\,23'\right)$$

$$+ \overset{\text{d.}}{18.2}\ \text{Sin.}\left(\frac{45^\circ}{11}E + 231^\circ\,42'\right) + \overset{\text{d.}}{33\ 9}\ \text{Sin.}\left(\frac{45^\circ}{22}E + 170^\circ\,19'\right)$$

$$+ \overset{\text{d.}}{65.3}\ \text{Sin.}\left(\frac{15^\circ}{11}E + 6^\circ\,37'\right):$$

Where E signifies the number of maxima which have occurred since Sept. 9, 1751, and the coefficients are given in days. Hence, for the year now in progress, we have the maximum:—

$$1751,\ \text{Sept. } 9,76 + \overset{\text{d.}}{36115{\cdot}65} + \overset{\text{d.}}{8{\cdot}44} - \overset{\text{d.}}{12{\cdot}24}$$
$$+ \overset{\text{d.}}{18.59} + \overset{\text{d.}}{27.34} = 1850,\ \text{Sept. } 8.54.$$

The circumstance which appears most in favour of this formula is, that it represents the observation of the maximum in 1596, (Kosmos, Bd. ii. S. 367; Eng. ed. p. 326—327), which, on the supposition of a uniform period, would deviate more than 100 days. Yet the law of the variations of light in this star is apparently so complicated, that in single cases (ex. gr. for the very exactly-observed maximum of the year 1840) the formula still deviates many days (almost 25).

([279]) p. 158.—Compare Argelander's Memoir at the secular festival of the Königsberg University, under the title of De Stella β Lyræ Variabili, 1844.

([280]) p. 159.—One of the first earnest endeavours to investigate the mean duration of the period of variability of Mira Ceti, is that of Jacques Cassini, Élémens d'Astronomie, 1740, p. 66—69.

([281]) p. 172.—Newton (Philos. Nat. Principia Mathem, ed. Le Sueur et Jacquier, 1760, T. iii. p. 671) distinguishes only two kinds of these sidereal phenomena: "Stellæ fixæ quæ per vices apparent et evanescunt quæque paulatim crescunt, videntur revolvendo partem lucidam et partem obscuram per vices ostendere." This explanation of the change of light had been previously proposed by Riccioli. Respecting the caution which should be exercised in assuming the existence of periodicity, see the important considerations of Sir John Herschel in the Cape Observations, § 261.

([282]) p. 172.—Delambre, Hist. de l'Astr. Ancienne, T. ii. p. 280; and Hist. de l'Astr. au 18ème siecle, p. 119.

([283]) p. 174.—Compare Sir John Herschel in the Cape Observations,

§ 71—78, and Outlines of Astronomy, § 830, (Kosmos, Bd. i. S. 160—416; Eng. ed., p. 144—Note, 120).

(284) p. 174.—Letter from Lieut. Gilliss to Dr. Flügel, Consul of the United States at Leipzic (MS.) The untroubled purity and serenity of the atmosphere at Santiago de Chile, lasting for 8 months, is so great that, with the *first* large telescope made in America, having an aperture of 6½ inches (constructed by Henry Fitz in New York and William Young in Philadelphia), Lieutenant Gilliss distinctly recognised the 6th star in the trapezium of Orion.

(285) p. 175.—Sir John Herschel, Cape Observations, p. 334—350, Note 1 and 440. (On older observations of Capella and $\alpha$ Lyræ, see William Herschel in the Phil. Trans. for 1797, p. 307, and for 1799, p. 121; and in Bode's Jahrbuch for 1810, S. 148). Argelander, on the other hand, entertains great doubts respecting the variability of Capella and of the stars in the Bear.

(286) p. 176.—Herschel's Cape Observations, § 259, No. 260.

(287) p. 176.—Heis, in manuscript notices in May 1850. Compare also Cape Observations, p. 325, and P. Von Boguslawski; "Uranus" for 1848, p. 186. (The assumed variability of $\eta$, $\alpha$, and $\delta$, Ursæ maj., is also supported in Herschel's Outlines, p. 559.) See Mädler Astr. S. 432, on the series of stars which are successively to mark the North Pole by their vicinity, until, at the end of 12,000 years, the place should be taken by the most brilliant of all possible pole-stars, $\alpha$ Lyræ.

(288) p. 176.—Kosmos, Bd. iii. S. 134; English edition, note 165.

(289) p. 176.—William Herschel, on the changes that happen to the fixed stars, in the Phil. Trans. for 1796, p. 186; Sir John Herschel in the Cape Observations, p. 350—352; and also in Mary Somerville's excellent work entitled Connexion of the Physical Sciences, 1846, p. 407.

(290) p. 178.—Encke, Betrachtungen über die Anordnung des Sternsystems, 1844, S. 12 (Kosmos, Bd. iii. S. 36, Engl. ed. p. 27); Mädler, Astr. S. 445.

(291) p. 180.—Halley in the Phil. Trans. for 1717—1719, Vol. xxx. p. 736. The consideration, however, referred only to variations in latitude; Jacques Cassini first added variations in longitude (Arago in the Annuaire pour 1842, p. 387).

(292) p. 180.—Delambre Hist. de l'Astr. Moderne, T. ii. p. 658; the same author in the Hist. de l'Astr. au 18ème siècle, p. 448.

(293) p. 181.—Phil. Trans. Vol. lxxiii. p. 138.

(294) p. 181.—Bessel in Schumacher's Jahrbuch for 1839, S. 38; Arago Annuaire for 1842, p. 389.

(295) p. 182.—See on $\alpha$ Centauri, Henderson and Maclear, in the Memoirs of the Astron. Soc. Vol. xi. p. 61; and Piazzi Smyth, in the Edinb. Trans. Vol. xvi. p. 447. The proper motion of Arcturus, 2″·25 (Baily, in the Memoirs of the Astr. Soc. Vol. v. p. 165), as belonging to a very bright star, may be called large in comparison with that of Aldebaran 0″·185 (Mädler, Central sonne S. 11), and that of $\alpha$ Lyræ 0″·400. Among stars of the 1st magnitude $\alpha$ Centauri, with its very large proper motion of 3″·58, forms a remarkable exception. The proper motion of the binary star-system in Cygnus, amounts according to Bessel (Schum. Astr. Nachr. Bd. xvi. S. 93), to 5″·123.

(296) p. 182.—Schumacher's Astr. Nach. No. 455.

(297) p. 182.—The same No. 618, S. 276. D'Arrest founds the result on comparisons of Lacaille (1750) with Brisbane (1825), and of Brisbane with Taylor (1835). The star 2151 Puppis has a proper motion of 7″·871, and is of the 6th magnitude (Maclear in Mädler's Unters. über die Fixstern-Systeme, Th. ii. S. 5).

(298) p. 182.—Schum. Astr. Nachr. No. 661, S. 201.

(299) p. 183.—The same, No. 514—516.

(300) p. 183.—Struve, Etudes d'Astr. Stellaire, Texte, p. 47, Notes, p. 26, and 51—57; Sir John Herschel, Outl. § 859 and 860.

(301) p. 184.—Origenes in Gronov. Thesaur. T. x. p. 271.

(302) p. 184.—Laplace, Expos. du Systeme du Monde, 1824, p. 395. Lambert, in his Cosmological Letters, shews a remarkable leaning to the assumption of dark cosmical bodies of great size.

(303) p. 184.—Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. (1848,) S. 3, and the same Author's Astronomie, S. 416.

(304) p. 185.—Compare Kosmos, Bd. iii. S. 96 and 130 (Engl. ed. p. 77—78, Note 149); Laplace, in Zach's Allg. Geogr. Ephem. Bd. iv. S. i.; Mädler, Astr. S. 393.

(305) p. 186.—Opere di Galileo Galilei, Vol. xii. Milano, 1811, p. 206. This remarkable passage, which expresses the possibility of a measurement, and a project for its execution, was discovered by Arago; see his Annuaire pour 1842, p. 382.

(306) p. 187.—Bessel, in Schumacher's Jahrb. für 1839, S. 5 and 11.

(307) p. 188.—Struve Astr. Stell. p. 104.

(308) p. 188.—Arago, in the Connaissance des tems pour 1834, p. 281:

"Nous observâmes avec beaucoup de soin, M. Mathieu et moi, pendant le mois d'août 1812, et pendant le mois de novembre suivant, la hauteur angulaire de l'étoile au-dessus de l'horizon de Paris. Cette hauteur, à la seconde époque, ne surpasse la hauteur angulaire de l'étoile au-dessus de l'horizon de Paris. Cette hauteur, à la seconde époque, ne surpasse la hauteur angulaire à la première que de 0″·66. Une parallaxe absolue d'une seule seconde aurait nécessairement amené entre ces deux hauteurs une difference de 1″·2. Nos observations n'indiquent donc pas que le rayon de l'orbite terrestre, que 39 millions de lieues soient vus de la 61eme du Cygne sous un angle de plus *d'une demi-seconde*. Mais une base vue perpendiculairement soutend un angle d'une demi-seconde quand on en est éloigné de 412 mille fois sa longueur. Donc la 61e du Cygne est *au moins* à une distance de la Terre égale à 412 mille fois 39 millions de lieues."

(309) p. 188.—Bessel published in Schum. Jahrb. 1839, S. 39-49, and in the Astr. Nachr. No. 366, the result 0″·3136, as a first approximation. His subsequent final result was 0″·3483 (Astr. Nachr. No. 402 in Bd. xvii. S. 274). Peters found by his own observations, the almost identical result of 0″·3490. (Struve, Astr. stell. p. 99.) The alterations which, after Bessel's death, Professor Peters made in that astronomer's calculation of the angular measurements obtained with the Königsberg Heliometer, were founded on the circumstance that Bessel himself (Astr. Nachr. Bd. xvii. S. 267) had promised to subject the influence of temperature on the results with the heliometer to a fresh examination, which intention he executed partially in the 1st Vol. of his "Astronomischen Untersuchungen," but did not apply the temperature correction to the observations of parallax. This application was made by Peters (Ergänzungsheft zu den Astr. Nachr. 1849, S. 56), and in consequence this distinguished astronomer found 0″·3744, instead of 0″·3483.

(310) p. 188.—This result of 0″·3744 gives, according to Argelander, the distance of the double star 61 Cygni from the Sun = 550900 mean distances of the Earth from the Sun, or 11394000 German (45576000 English) geographical miles; a distance which light traverses in 3177 mean days. By the three successive assignments of parallax given by Bessel, 0″·3136, 0″·3483, and 0·3744, this star has come (apparently) gradually nearer to us; they correspond respectively to light-passages of 10, $9\frac{1}{4}$, and $8\frac{7}{10}$ years.

(311) p. 188.—Sir John Herschel, Outlines, p. 545 and 551. Mädler (Astr. S. 425) gives for *α* Centauri, instead of 0″·9128, the parallax 0″·9213.

(312) p. 189.—Struve, Stell. compos. Mens. microm. p. clxix.—clxxii. Airy considers the parallax of *α* Lyræ, which Peters has already diminished

to 0″·1, to be still less; *i. e.* to be too small for measurement with our present instruments (Mem. of the Royal Astr. Soc. Vol. x. p. 270).

(313) p. 189.—Struve on Micrometer-measurements in the large refractor of the Dorpat Observatory (Oct. 1839) in Schum. Astr. Nachr. No. 396, S. 178.

(314) p. 189.—Peters in Struve's Astr. stell. p. 100.

(315) p. 189.—Idem, p. 101.

(316) p. 191.—On the relation of the amount of proper motion to the proximity of the brightest stars, compare Struve, Stell. compos. Mensuræ microm. p. clxiv.

(317) p. 192.—Savary, in the Connaissance des Tems pour 1830, p. 56—69, and p. 163—171; and Struve, Stell. compos. Mensuræ microm. p. clxiv.

(318) p. 193.—Kosmos, Bd. i. S. 150 and 414; English edition, p. 134, and xxxvii. note 101.

(319) p. 193.—Mädler, Astronomie, S. 414.

(320) p. 193.—Arago (Annuaire pour 1842, p. 383) first called attention to this remarkable passage of Bradley; compare in the same Annuaire the section on the movement of translation of the entire solar system, p. 389—399.

(321) p. 195.—According to a letter to myself, see Schum. Astr. Nachr. No. 622, S. 348.

(322) p. 195.—Galloway on the Motion of the Solar System, in the Phil. Trans. 1847, p. 98.

(323) p. 196.—The value or otherwise of such views is discussed by Argelander in a memoir entitled Über die eigene Bewegung des Sonnensystems, hergeleitet aus der eigenen Bewegung der Sterne, 1837, S. 39, "on the proper motion of the solar system, deduced from the proper motion of stars," p. 39.

(324) p. 197.—Compare Kosmos, Bd. i. S. 149 (English edition, p. 134), and Mädler's Astr. S. 400.

(325) p. 197.—Argelander, work above quoted, S. 42; Mädler Centralsonne, S. 9, and Astr. S. 403.

(326) p. 197.—Argelander, last cited work, S. 43, and in Schum. Astr. Nachr. No. 566. Guided not by numerical investigations, but only by fanciful conjectures, Kant had taken Sirius, and Lambert the Nebula in Orion's belt, for the central body of our sidereal stratum. Struve Astr. stell. p. 17, No. 19.

(327) p. 197.—Mädler, Astr. S. 380, 400, 407, and 414; his Centralsonne 1846, S. 44—47; his Untersuchungen über die Fixstern Systeme, Th. ii. 1848, S. 183—185 (Alcyone is in R. A. 54° 30′, Decl. 23° 36′, for the year

1840. If the parallax of Alcyone were really 0″·0065, then its distance would amount to 31½ million times the semi-diameter of the Earth's orbit; thus it would be fifty times more distant from us than the double star 61 Cygni, according to Bessel's earliest determination. Light which comes from the Sun to the Earth in 8′ 18″·2, would require 500 years to travel from Alcyone to the Earth. The Imagination of the Greeks delighted in wild estimations of space fallen through. In Hesiod's Theogony, v. 722—725, it is said, speaking of the fall of the Titans to Tartarus, "When once an iron anvil fell from heaven, nine days and nights it fell, and on the tenth it reached the Earth." To this fall taking place in 777600 seconds of time, the corresponding distance (taking into account, according to Galle's calculation, the great decrease of the Earth's attractive force at planetary distances) is 77356 German (309424 English) geographical miles, or once and a half the distance from the Moon to the Earth. But according to Homer, Il. i. 952, Hephæstos fell down to Lemnos in only one day, and merely "still breathed a little." The length of the chain hanging down from Olympus to the Earth, by which all the gods were to essay to draw Zeus down (Il. viii. 18), is left indefinite. It is an image intended to express, not the height of heaven, but the strength and surpassing might of Jupiter.

(328) p. 198.—Compare the doubts expressed by Peters in Schum. Astr. Nachr. 1849, S. 661, and by Sir John Herschel in the Outlines of Astr. p. 589. "In the present defective state of our knowledge respecting the proper motion of the smaller Stars, we cannot but regard all attempts of the kind as to a certain extent premature, though by no means to be discouraged as forerunners of something more decisive."

(329) p. 199.—Compare Kosmos, Bd. i. S. 152—154 and 414 (Eng. ed. p. 136—138, and xxxvii.) (Struve über Doppelsterne nach Dorpater Micrometer-Messungen von 1824 bis 1837, S. 11).

(330) p. 200.—Kosmos, Bd. iii. S. 64—67, 110—113 and 166—168 (Eng. ed. p. 47—50, and 108—110). As remarkable examples of visual power in particular individuals, I may mention that Kepler's instructor, Möstlin, saw with the naked eye 14, and some of the Ancients 9, stars in the group of the Pleiades. (Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. S. 36.)

(331) p. 200.—Kosmos, Bd. iii. S. 271 (Eng. ed. p. 185.) Dr. Gregory of Edinburgh also recommended the same method in 1675 (33 years therefore after Galileo's death); compare Thomas Birch, Hist. of the Royal Society, Vol. iii. 1757, p. 225. Bradley (1748) alludes to this method at the end of his celebrated treatise on Nutation.

([332]) p. 201 —Mädler, Astr. S. 447.

([333]) p. 201.—Arago in the Annuaire for 1842, p. 400.

([334]) p. 201.—"An Inquiry into the probable Parallax and Magnitude of the fixed Stars, from the quantity of light which they afford us, and the particular circumstances of their situation, by the Rev. John Michell; in the Phil. Trans. Vol. lvii. p. 234—261.

([335]) p. 202.—John Michell, same work, p. 238. "If it should hereafter be found, that any of the stars have others revolving about them (for no satellites by a borrowed light *could possibly be visible*), we should then have the means of discovering . . . ." He denies throughout the whole discussion, that one of two revolving stars can be a dark planet, reflecting light not its own, since both are visible to us notwithstanding the distance. He compares both the stars, the larger of which he calls the "Central Star," with the density of our sun, and applies the term "Satellite" only for the purpose of conveying the idea of revolution, or reciprocal motion. He speaks of the "greatest apparent elongation of those stars that revolved about the others as satellites." Further on he says, "We may conclude with the highest probability (the odds against the contrary opinion being many million millions to one) that stars form a kind of system by mutual gravitation. It is highly probable in particular, and next to a certainty in general, that such double stars as appear to consist of two or more stars placed near together, are under the influence of some general law, such perhaps as gravity." (Compare also Arago in the Ann. 1834, p. 308, and in the Ann. 1842, p. 400.) No great weight can be ascribed to the numerical results of the calculus of probabilities, as given by Michell, taken separately; as the suppositions laid down, that there are in the entire heavens 230 stars equal in intensity of light to $\beta$ Capricorni, and 1500 equal to the light of the six larger Pleiades, are not at all correct. The ingenious cosmological memoir of John Michell terminates with the very hazardous attempt to explain the scintillation of the fixed stars by a kind of "pulsation in material effluxes of light," an attempt as little fortunate as that put forth by Simon Marius, one of the discoverers of Jupiter's satellites (Kosmos, Bd. ii. S. 357 and 509, Eng. ed. p. 316, note 484) at the end of his Mundus Jovialis (1614). Michell, however, has the merit of having called attention (p. 263) to the circumstance that scintillation is always combined with change of colour; "besides their brightness, there is in the twinkling of the fixed stars a change of colour." (See Kosmos, Bd. iii. S. 122, Eng. ed. note 129.)

([336]) p. 203.—Struve in the Recueil des Actes de la Séance publique de

l'Acad. Imp. des Sciences de St. Petersbourg, le 29 déc. 1832, p. 48—50; Mädler, Astr. S. 478.

(337) p. 203.—Phil. Trans. for the year 1782, p. 40—126; for 1783, p. 112—124, for 1804, p. 87. On the observational basis of the 846 double stars of Sir William Herschel, compare Mädler in Schumacher's Jahrbuch für 1839, S. 59, and the same author's Untersuchungen über die Fixstern-Systeme, Th. i. 1847, S. 7.

(338) p. 205.—Mädler in the last-named work, Th. i. S. 255. We have for Castor, two old observations of Bradley's, 1719 and 1759, the first taken conjointly with Pond's, the second with Maskelyne's, and two of William Herschel's, of 1799 and 1803. For the time of revolution of λ Virginis, see Mädler, Fixstern-Syst., Th. ii. 1848, S. 234—240.

(339) p. 205.—Struve, Mensuræ microm., p. xl. and p. 234—248. There are, in all, 2641 + 146; therefore, 2787 observed multiple stars. (Mädler, in Schum. Jahrb. 1839, S. 64).

(340) p. 205.—Sir John Herschel, Astron. Observ. at the Cape of Good Hope, p. 165—303.

(341) p. 206.—Idem, p. 167 and 242.

(342) p. 206.—Argelander, in examining a large number of fixed stars for a most careful investigation of their proper motion. See his memoirs, DLX Stellarum fixarum positiones mediæ ineunte anno 1830, ex observ. Aboæ habitis (Helsingforsiæ, 1825). Mädler (Astr. S. 625), estimates at 600 the number of multiple stars discovered in the northern celestial hemisphere at Pulkova since 1837.

(343) p. 247.—The number of fixed stars in which *proper motion* has been perceived (while we may conjecture its existence in all), is a little greater than the number of multiple stars in which a *difference of relative position* has been observed. Mädler, Astr. S. 394, 490, and 520—540. Struve, in his Mens. micróm., p. xciv., gives the results of the application of the calculus of probabilities to these relations, according as the distances apart of the double or multiple stars are between 0″ and 1″, 2″ and 8″, or 16″ and 32.″ Distances less than 0″·8 have been appreciated, and experiments with very closely placed artificial double stars have confirmed the observer's hopes of such estimations being for the most part secure, as far as 0″.1. Struve über Doppelsterne nach Dorpater Beob. S. 29.

(344) p. 208.—John Herschel, Cape Observations, p. 166.

(345) p. 208.—Struve Mensuræ microm., p. lxxvii. to lxxxiv.

(346) p. 208.—John Herschel, Outlines of Astr., p. 579.

([347]) p. 208.—Two glasses, presenting complementary colours, being placed over each other, give a white image of the Sun. During my long stay at the Paris Observatory, my friend Arago employed this arrangement with great advantage, in the place of the ordinary shade-glasses, for observations of solar eclipses, and of the Sun's spots. The colours to be taken are—red and green, yellow and blue, or green and violet. " Lorsqu'une lumière forte se trouve auprès d'une lumière faible, la dernière prend la teinte *complémentaire* de la première. C'est là le *contraste:* mais comme le rouge n'est presque jamais pur, on peut tout aussi bien dire que le rouge est complémentaire du bleu. Les couleurs voisines du Spectre solaire se substituent." (Arago, MS. of 1847).

([348]) p. 209. —Arago in the Connaissance des Tems pour l'an 1828, p. 299—300, and pour 1834, p. 246—250, and pour 1842, p. 347—350. " Les exceptions que je cite, prouvent que j'avais bien raison en 1825 de n'introduire la notion physique du *contraste* dans la question des étoiles doubles qu'avec la plus grande réserve. Le bleu est la couleur rèelle de certaines étoiles. Il résulte des observations recueillies jusqu'içi que le firmament est non seulement parsemé de soleils *rouges* et *jaunes*, comme le savaient les Anciens, mais encore de soleils *bleus* et *verts*. C'est au tems et à des observations futures à nous apprendre si les étoiles vertes et bleues ne sont pas des soleils déjà en voie de décroissance; si les differentes nuances de ces astres n'indiquent pas que le combustion s'y opère à différens degrés; si la teinte, avec excès de rayons les plus réfrangibles, que presente souvent la petite étoile, ne tiendrait pas à la force absorbante d'une atmosphère que developperait l'action de l'étoile, ordinairement beaucoup plus brillante, qu'elle accompagne.—(Arago in the Annuaire for 1834, p. 295—301.

([349]) p. 209.—Struve über Doppelsterne nach Dorpater Beobachtungen, 1837, S. 33—36, and Mensuræ microm. p. lxxxiii., enumerates sixty-three pairs of stars, in which both stars are blue or bluish, and in which, therefore, the colour cannot be the result of contrast. When it is necessary to compare together the colours of the same double stars, as given by different observers, it is particularly striking to remark how often the companion of a red or yellowish red star is called *blue* by one observer, and *green* by another.

([350]) p 209.—Arago in the Annuaire for 1834, p. 302.

([351]) p. 209.—Kosmos, Bd. iii. S. 168—172; Eng. ed. p. 110—114.

([352]) p. 210.—" This superb double star ($\alpha$ Centauri) is beyond all comparison the most striking object of the kind in the heavens, and consists of

two individuals, both of a high ruddy or orange colour, though that of the smaller is of a somewhat more sombre and brownish cast." Sir John Herschel, Cape Observations, p. 300. According to the valuable observations of Captain Jacob, of the Bombay Engineers, in 1846—1848, the principal star is estimated at the 1st magnitude, and the companion from the 2·5 to the 3rd magnitude.

(353) p. 210.—Kosmos, Bd. iii. S. 235, 249 and 259, Eng. ed. pp. 155, 249, and note 274.

(354) p. 211.—Struve über Doppelst. nach Dorpat. Beob. S. 33.

(355) p. 211.—Same work, S. 36.

(356) p. 211.—Mädler, Astr. S. 517; John Herschel, Outlines, p. 568.

(357) p. 211.—Compare Mädler, Untersuch. über die Fixstern-Systeme, Th. i. S. 225—275, Th. ii. S. 235—240; the same Author, in hi Astr. S. 541; and John Herschel, Outlines, p. 573.

(358) p. 215.—Kosmos, Bd. i. S. 86—91 and 158 (English edition, p. 74—79 and 142); Bd. ii. S. 369 (English edit. p. 328); Bd. iii. S. 47—51, 178, 219, and 231 (English edit. p. 37—41, 120, 136, and 150).

(359) p. 215.—Kosmos, Bd. iii. S. 267—269 (Engl. edit. p. 182—183).

(360) p. 217.—Kosmos, Bd. i. S. 87 (Engl. edit. p. 75).

(361) p. 218.—Kosmos, Bd. iii. S. 99, 131, Anm. 62; 178 and 210, Anm. 71: Engl. edit. p. 80, Note 151; p. 119, Note 237.

(362) p. 219.—Before the expedition of Alvaro Becerra. The Portuguese advanced in 1471 to the South of the Equator. See Humboldt, Examen critique de l'Hist. de la Géogr. du Nouveau Continent, T. i. p. 290—292. On the Eastern side of Africa, the commercial route through the Indian Ocean from Ocelis on the Straits of Bab-el-Mandeb to the Entrepot of Muzeris on the Malabar coast and to Ceylon, being favoured by the south-west monsoon (Hippalus), was frequented under the Ptolemies (Kosmos, Bd. ii. S. 203 and 433, Note 21; Engl. edit. p. 169, Note 261). On all these routes the Magellanic clouds must have been seen, although they have not been described.

(363) p. 219.—Sir John Herschel, Cape Observations, § 132.

(364) p. 219.—Kosmos, Bd. ii. S. 357 and 509, Note 43. Galileo, who sought to attribute the difference between the days of discovery (29 Dec. 1609, and 7 Jan. 1610) to the difference of calendars, in his wrath at what he terms the "bugia del impostore *eretico Guntzenhusano*," goes so far as to declare "che molto probabilmente il Eretico Simon Mario non ha osservato giammai i Pianeti Medicei" (see Opere di Galileo Galilei, Padova, 1744, T. ii. p. 235

—237; and Nelli, Vita e Commercio Letterario di Galilei, 1793, Vol. i. p. 240—246). Yet the "Eretico" had expressed himself in a very modest and peaceable manner respecting the measure of his own merit in the discovery. "I merely maintain," said Simon Marius in the Preface to the Mundus Jovialis, "that, hæc sidera (Brandenburgica) a nullo mortalium mihi ulla ratione commonstrata, sed propria indagine sub ipsissimum fere tempus, vel aliquanto citius quo Galilæus in Italia ea primum vidit, a me in Germania adinventa et observata fuisse. Merito igitur Galilæo tribuitur et manet laus primæ inventionis horum siderum apud Italos. An autem inter meos Germanos quispiam ante me ea invenerit et viderit, hactenus intelligere non potui."

([365]) p. 219.—"Mundus Jovialis anno 1609 detectus ope perspicilli Belgici," Norібergæ, 1614.

([366]) p. 220.—Kosmos, Bd. ii. S. 368 (Engl. edit. p. 327).

([367]) p. 220.—Kosmos, Bd. iii. S. 180 (Engl. edit. p. 122).

([368]) p. 221.—"Galilei notò che le Nebulose di Orione null' altro erano che mucchi e coacervazioni d' innumerabili Stelle" (Nelli, Vita di Galilei, Vol. i. p. 208).

([369]) p. 221.—"In primo integram Orionis constellationem pingere decreveram; vero, ab ingenti stellarum copia, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli.—Cum non tantum in Galaxia lacteus ille candor veluti albicantis nubis spectetur, sed *complures consimilis coloris areolæ sparsim per æthera subfulgeant,* si in illarum quamlibet specillum convertas, Stellarum constipatarum coetum offendes. Amplius (quod magis mirabile) Stellæ, ab Astronomis singulis in hanc usque diem *Nebulosæ* appellatæ, Stellarum mirum in modum consitarum greges sunt: ex quarum radiorum commixtione, dum unaquaque ob exilitatem seu maximam a nobis remotionem, oculorum aciem fugit, candor ille consurgit, qui densior pars cœli, Stellarum aut Solis radios retorquere valens, hucusque creditus est." —Opere di Galileo Galilei, Padova, 1744, T. ii. p. 14—15; Sidereus Nuncius, pp. 15, 15 (No. 19—21), and 35 (No. 56).

([370]) p. 221.—Compare Kosmos, Bd. iii. S. 106. I would also recall the vignette at the conclusion of the Introduction of Hevelii Firmamentum Sobescianum, 1687, in which three genii are seen, two of whom are observing with the sextant of Hevelius; while to the third genius, who carries a telescope and appears to offer it, the observers answer: Præstat nudo oculo!

([371]) p. 221.—Huygens, Systema Saturnium, in his Opera varia, Lugd. Bat. 1724, T. ii. p. 523 and 593.

([372]) p. 222.—"Dans les deux nébuleuses d'Andromède et d'Orion," says Dominique Cassini, "j'ai vu des étoiles qu'on n'aperçoit pas avec des lunettes communes. Nous ne savons pas si l'on ne pourroit pas avoir des lunettes assez grandes pour que toute la nébulosité pût se résondre en de plus petites étoiles, comme il arrive à celles du Cancer et du Sagittaire" (Delambre, Hist. de l'Astr. moderne, T. ii. p. 700 and 744).

([373]) p. 222.—Kosmos, Bd. i. S. 412, Anm. 66 (Engl. edit. Note 96).

([374]) p. 223.—On the ideas of Lambert and Kant viewed in connection with each other,—what they had in common, and wherein they differed,—as well as on the dates of their publications, see Struve, Etudes d'Astr. stellaire, p. 11, 13, and 21; Notes 7, 15, and 33. Kant's "Allgemeine Naturgeschichte und Theorie des Himmels" (General History of Nature and Theory of the Heavens) appeared anonymously, and with a dedication to the King of Prussia, in 1755; Lambert's "Photometria," as has been already remarked, appeared in 1760, and his "Sammlung kosmologischer Briefe über die Einrichtung des Weltbaues" (Collection of Cosmological Letters on the Structure of the Universe) in 1761.

([375]) p. 223.—"Those nebulæ," said John Michell, 1767 (Phil. Trans. Vol. lvii. for 1767, p. 251), "in which we can discover either none or only a few stars even with the assistance of the best telescopes, are probably systems, that are still more distant than the rest."

([376]) p. 224.—Messier, in the Mém. de l'Académie des Sciences, 1771, p. 435; and in the Connaissance des Temps pour 1783 and 1784. The whole list contains 103 objects.

([377]) p. 224.—Phil. Trans. Vol. lxxvi., lxxix., and xcii.

([378]) p. 224.—"The nebular hypothesis, as it has been termed, and the theory of sidereal aggregation, stand in fact quite independent of each other" (Sir John Herschel, Outlines of Astronomy, § 872, p. 599).

([379]) p. 225.—The numbers in the text are those of the objects enumerated from No. 1 to 2307 in the European or Northern Catalogue of 1833, and from No. 2308 to 4015 in the African or Southern Catalogue (Cape Observations, p. 51—128).

([380]) p. 225.—James Dunlop, in the Phil. Trans. for 1828, p. 113—151.

([381]) p. 225.—Compare Kosmos, Bd. iii. S. 81 and 117, Anm. 34 (English edit. p. 63, Note 123).

([382]) p. 225.—"An Account of the Earl of Rosse's Great Telescope," p. 14—17, in which the list of the nebulæ resolved in March 1845 by Dr. Robinson and Sir James South, is given. "Dr. Robinson could not leave

this part of his subject without calling attention to the fact, that no real nebula seemed to exist among so many of these objects, chosen without any bias: all *appeared* to be clusters of stars, and every additional one which shall be resolved will be an additional argument against the existence of any such" (Schumacher, Astr. Nachr. No. 536). In the "Notice sur les grands Télescopes de Lord Oxmantown, aujourd'hui Earl of Rosse" (Bibliothèque universelle de Genève, T. lvii. 1845, p. 342—357), it is said: "Sir James South rappelle que jamais il n'a vu de représentations sidérales aussi magnifiques que celles que lui offrait l'instrument de Parsonstown; qu'une bonne partie des nébuleuses se presentaient comme des amas ou groupes d'étoiles, tandis que quelques autres, à ses yeux du moins, n'offraient aucune apparence de résolution en étoiles."

(383) p. 226.—Report of the Fifteenth Meeting of the British Association held at Cambridge in June 1845, p. xxxvi.; and Outlines of Astronomy, p. 597 and 598. "By far the major part," says Sir John Herschel, "probably at least nine-tenths of the nebulous contents of the heavens, consist of nebulæ of spherical or elliptical forms, presenting every variety of elongation and central condensation. Of these, a *great number* have been resolved into distant stars (by the Reflector of the Earl of Rosse), and a vast number more have been found to possess that mottled appearance which renders it almost a matter of certainty that an increase of optical power would show them to be similarly composed. A not unnatural or unfair induction would therefore seem to be, that those which resist such resolution do so only in consequence of the smallness and closeness of the stars of which they consist; that in short they are only optically and not physically nebulous.—Although nebulæ do exist which even in this powerful telescope (of Lord Rosse) appear as nebulæ without any sign of resolution, it may very reasonably be doubted whether there be really any essential physical distinction between nebulæ and clusters of stars."

(384) p. 226.—Dr. Nichol, Professor of Astronomy at Glasgow, has published in his "Thoughts on some Important Points relating to the System of the World," 1846, p. 55, this letter, dated Castle, Parsonstown: "In accordance with my promise of communicating to you the result of our examination of Orion, I think I may safely say, that there can be little, if any, doubt as to the resolvability of the nebula. Since you left us, there was not a single night when, in the absence of the moon, the air was fine enough to admit of our using more than half the magnifying power the speculum bears: still we could plainly see that all about the trapezium is a mass of stars; the rest of

the nebula also abounding with stars, and exhibiting the characteristics of resolvability strongly marked."

(385) p. 227.—Compare Edinburgh Review, Vol. lxxxvii. 1848, p. 186.

(386) p. 227.—Kosmos, Bd. iii. S. 183 and 212, Anm. 84 (English edit. p. 125, Note 250).

(387) p. 227.—Kosmos, Bd. iii. S. 44 (English edit. p. 35).

(388) p. 228.—Newton, Philos. Nat., Principia mathematica, 1760, T. iii. p. 671.

(389) p. 228.—Kosmos, Bd. i. S. 146 (Engl. edit. p. 131).

(390) p. 228.—Kosmos, Bd. i. S. 412, Anm. 66 (Engl. edit. Note 96).

(391) p. 228.—Sir John Herschel, Cape Observations, § 109—111.

(392) p. 229.—It may be proper to explain here the grounds on which this enumeration is based. The three Catalogues of Sir William Herschel contain 2500 objects; viz. 2303 nebulæ, and 197 star-clusters (Mädler, Astr. S. 448). These numbers underwent alteration in a later and much more exact review of the heavens by Sir John Herschel (Observations of Nebulæ and Clusters of Stars made at Slough with a Twenty-feet Reflector, between the years 1825 and 1833: Phil. Trans. 1833, p. 365—481). About 1800 objects were identical with those of the three earlier catalogues; but from three to four hundred were provisionally excluded, and more than five hundred newly discovered ones had their Right Ascension and Declination determined (Struve, Astr. stellaire, p. 48). The Northern catalogue contains 152 clusters of stars, consequently $2307-152=2155$ nebulæ; but in the Southern catalogue (Cape Observ. p. 3, § 6 and 7) we have to deduct from $4015-2307=1708$ objects (among which there are 236 star-clusters) 233 (viz. $89+135+9$: see Cape Observ. p. 3, § 6 and 7, and p. 128) as belonging to the Northern catalogue, observed by Sir William and Sir John Herschel at Slough, and by Messier at Paris. There thus remain for the Cape Observations, $1708-233=1475$ nebulæ and clusters, or 1239 nebulæ only. To the 2307 objects of the Northern catalogue of Slough we have to add, on the other hand, $135+9=144$. Thus this Northern list becomes increased to 2451 objects, containing, after deducting 152 clusters, 2299 nebulæ; which numbers, however, do not apply to a very strict limit of the horizon according to the height of the Pole at Slough. If in the topography of the firmament it is deemed proper to assign numerical ratios to the two hemispheres, the author thinks that it is right to do so carefully, although the numbers in question must always be expected to vary at different epochs, and according to the progress of observation. It belongs to the general design of

the present work to attempt to depict the state of knowledge at a determinate epoch.

(393) p. 229.—Sir John Herschel says, in p. 134 of his Cape Observations, "There are between 300 and 400 nebulæ of Sir William Herschel's Catalogue still unobserved by me,—for the most part very faint objects." . . . .

(394) p. 229.—Cape Observ. § 7. (Compare Dunlop's Catalogue of Nebulæ and Clusters of the Southern Hemisphere, in the Phil. Trans. for 1828, p. 114—146.)

(395) p. 230.—Kosmos, Bd. iii. S. 297 (Engl. edit. p. 206—207.)

(396) p. 230.—Cape Observ. § 105—107.

(397) p. 231.—In Kosmos, Bd. iii. S. 181, line 6 from below, by an error of the press, the words South Pole and North Pole have been interchanged [this was rectified in the English edition, p. 124, line 8 from top].

(398) p. 231.—"In this *region* of '*Virgo*,' occupying about one-eighth of the whole surface of the sphere, one-third of the entire nebulous contents of the heavens are congregated" (Outlines, p. 596).

(399) p. 231.—On this "barren region" see Cape Observ. § 101, p. 135.

(400) p. 232.—I found these numerical data on the summing up of the numbers furnished by the projection of the northern heavens, in the Cape Observ. Pl. xi.

(401) p. 233.—Humboldt, Examen crit. de l'Hist. de la Géographie, T. iv. p. 319. In the long series of voyages undertaken under the influence of the Infante Don Henrique by the Portuguese along the West coast of Africa towards the Equator, the Venetian Cadamosto (whose proper name was Alvise da Ca da Mosto), after joining Antoniotto Usodimare at the mouth of the Senegal in 1454, was the first who occupied his attention with the search after a southern Pole-star. "As," said he, "I still see the northern Pole-star" (he was in about 13° North latitude), I cannot see the south one itself; but the constellation which I see farthest towards the South is the Carro del Ostro (the Southern Wain or Car)." (Aloysii Cadam. Navig. cap. 43, p. 32; Ramusio, Delle Navigazioni et Viaggi, Vol. i. p. 107). May he have formed for himself a car or wain from some large stars of the constellation of the Ship? The idea that each of the two Poles had its car, appears to have been so prevalent at that time, that in the Itinerarium Portugallense, 1508, fol. 23, *b*, and in Grynäus, Novus Orbis, 1532, p. 58, there is a constellation, quite similar to the Little Bear, figured as having been seen by Cadamosto; while Ramusio (Navigationi, Vol. i. p. 107) and the new Collecção de Noticias para a hist. e geogr. das Nacoes Ultramarinas (T. ii. Lisboa, 1812, p. 57, cap. 39)

figure instead, but in an equally arbitrary manner, the Southern Cross (Humboldt, Examen crit. de l'Hist. de la Géogr. T. v. p. 236). As it was usual in the Middle Ages to seek to replace the two dancers (χορευται) of Hyginus (Poet. astron. iii. 1), *i. e.* the Ludentes of the scholiast, to Germanicus, or Custodes of Vegetius, in the Little Bear,—the stars β and γ of that constellation were made into the Guards (le due Guardie) of the North Pole, near to which they are situated, and round which they revolve; and as this name of the "two Guards," as well as the use made of them for determining the height of the Pole (Pedro de Medina, Arte de Navegar, 1545, libro v. cap. 4—7, p. 183—195), had become general among the navigators of all European nations in the Northern Seas—so, erroneous inferences of analogy led men to think they discovered on the southern horizon what they had long before sought for there. When Amerigo Vespucci, on his second voyage from May 1499 to Sept. 1500, and Vicente Yañez Pinzon (both whose voyages are perhaps the same), arrived as far south in the Southern Hemisphere as Cape San Augustin, they first began to occupy themselves diligently, but vainly, in seeking for a star visible in the immediate vicinity of the Southern Pole (Bandini, Vita e Lettere di Amerigo Vespucci, 1745, p. 70; Anghiera, Oceanica, 1510, Dec. I. lib. ix. p. 96; Humboldt, Examen crit. T. iv. p. 205, 319, and 325). The South Pole of the heavens was then in the constellation of the Octant, so that β Hydræ minoris, if we make the reduction according to Brisbane's Catalogue, had still fully 80° 5′ South Declination. Vespucci, in a letter addressed to Pietro Francesco de' Medici, said: "Whilst I was occupied with the wonders of the southern heavens, and seeking amongst them in vain for a southern Pole-star, I remembered a few words of our Dante, where, in the first chapter of the Purgatorio, supposing himself passing from one hemisphere to the other, and intending, I believe, to describe the Antarctic Pole, he sings—

"Io mi volsi a man destra" . . . . .

I feel the more certain that the poet meant to indicate by his four stars (non viste mai fuor ch' alla prima gente) the Pole of the other firmament, because I saw in reality four stars which, together, formed a 'mandorla,' and had a small (?) motion." Vespucci meant the Southern Cross, the Croce maravigliosa of Andrea Corsali (Letter from Cochin of the 6th of January, 1515, in Ramusio, Vol. i. p. 177), with the name of which he was not yet acquainted, and which subsequently was made use of by all navigators (like β and γ of

the Little Bear, in the case of the North Pole) for finding the Southern Pole (Mém. de l'Acad. des Sciences, 1666—1699, T. vii. Part 2, Paris, 1729, p. 58), and for determinations of latitude (Pedro de Medina, Arte de Navegar, 1545, libro v. cap. xi. p. 204). Compare what I have said on the subject of Dante's famous passage in my Examen crit. de l'Hist. de la Géogr. T. iv. p. 319—334. I also remarked there that $\alpha$ Crucis, with which in modern times Dunlop in 1826, and Rumker in 1836, occupied themselves at Paramatta, is one of the stars earliest recognised, in 1681 and 1687, by the Jesuit Fontaney, and by Noel and Richaud, as multiple stars (Hist. de l'Acad. dep. 1686—1699, T. ii. Par. 1733, p. 19; Mem. de l'Acad. dep. 1666—1699, T. vii. 2, Par. 1729, p. 206; Lettres édifiantes, Recueil vii. 1703, p. 79). Such early recognition of binary systems, long before the double star $\zeta$ Ursæ maj. was recognised as such (Part I. of present volume, p. 201), is the more remarkable, because seventy years afterwards Lacaille did not describe $\alpha$ Crucis as a double star,—possibly, as conjectured by Rumker, because the principal star and its companion were at that time at too small a distance apart. (Compare Sir John Herschel, Cape Observations, § 183—185.) Almost at the same time that the double character of $\alpha$ Crucis was discovered, that of $\alpha$ Centauri was also recognised by Richaud nineteen years before the voyage of Feuillée, to whom this discovery has been erroneously ascribed by Henderson. Richaud remarked that, "at the time of the comet of 1689, the two stars which form the double star $\alpha$ Crucis were at a considerable distance apart; but that the two components of $\alpha$ Centauri, although, when viewed through a twelve-feet refractor, they might indeed be clearly recognised as distinct, yet appeared almost to touch each other."

(402) p. 234.—Cape Observations, § 44 and 104.

(403) p. 234.—Kosmos, Bd. iii. S. 179 and 211 (Engl. edit. p. 120, and Note 240). Yet, as has been already remarked in treating, in the first part of the present volume (p. 122), of star-clusters. Mr. Bond, of the United States of North America, has succeeded, by the extraordinary space-penetrating power of his refractor, in entirely resolving the long drawn out elliptical nebula in Andromeda, which, according to Bouillaud, had been described before Simon Marius, in 985 and in 1428, and which has a reddish light. In the vicinity of this celebrated nebula there is another, still unresolved, but very closely resembling it in form, discovered on the 27th of August, 1783, by my friend the late Miss Caroline Herschel, who died at a highly advanced age, honoured by all. (See Phil. Trans. 1833, No. 61 of the list of nebulæ, fig. 52).

([404]) p. 235.—Annular nebula: (Cape Observ. p. 53; Outlines of Astr. p. 602); Nébuleuse perforée: (Arago, in the Annuaire for 1842, p. 423); Bond, in Schum. Astr. Nachr. No. 611.

([405]) p. 235.—Cape Observations, p. 114, Pl. vi. fig. 3 and 4; compare also No. 2072, in the Phil. Trans. for 1833, p. 466. See Lord Rosse's drawings of the ring-nebula in Lyra, and of the singular crab-nebula in Nichol's "Thoughts on the System of the World," p. 21, Pl. iv.; and p. 22, Pl. i. fig. 5.

([406]) p. 236.—Regarding the planetary nebula in Ursa major as a sphere, and supposing it placed at a distance from us not more than that of 61 Cygni, its apparent diameter of 2′ 40″ would imply an actual diameter seven times greater than that of the orbit of Neptune (Outlines, § 876).

([407]) p. 236.—Outlines, p. 603; Cape Observations, § 47. An orange-red star of the 8th magnitude is near No. 3365, but the planetary nebula still appears of a deep indigo-blue when the red star is not in the field of the telescope: the colour is therefore not the effect of contrast.

([408]) p. 236.—Kosmos, Bd. iii. S. 173, 299, and 309 (Engl. edit. p. 115, 208—209, Note 348). In more than 63 double stars the companion and the principal star are both blue or bluish. Small indigo-blue stars are intermingled in the superb many-coloured star-cluster No. 3435 of the Cape Catalogue (Dunlop's Cat. No. 301). There is an entirely uniform blue cluster of stars in the southern heavens (No. 573 of Dunlop, No. 3770 of John Herschel). It has 3½′ diameter, with projections which run out to 8′ of length: the stars are from the 16th to the 14th magnitude (Cape Observ. p. 119).

([409]) p. 236.—Kosmos, Bd. i. S. 88 and 387 (Engl. edit. p. 76, Note 31). Compare Outlines, § 877.

([410]) p. 236.—On the complexity of the dynamic relations in the partial attractions in the interior of a spherically round star-cluster, which in weak telescopes appears as a round nebula denser towards the centre, see Sir John Herschel, in Outlines of Astronomy, § 866 and 872; Cape Observ. § 44 and 111—113; Phil. Trans. for 1833, p. 501; and Address of the President in the Report of the Fifteenth Meeting of the British Association, 1845, p. xxxvii.

([411]) p. 237.—Mairan, Traité de l'Aurore boréale, p. 263 (Arago, in the Annuaire for 1842, p. 403—413).

([412]) p. 238.—Other instances of nebulous stars are only from the 9th to the 8th magnitude; as, for example, No. 311 and No. 450 of the Catalogue of 1833, fig. 31, with photospheres of 1′ 30″ (Outlines, § 879).

([413]) p. 238.—Cape Observations, p. 117, No. 3727, Pl. vi. fig. 16.

([414]) p. 238.—The following may be cited as remarkable forms of irregular nebulæ :—the one resembling the letter Omega (see Cape Observ. Pl. ii. fig. 1, No. 2008, and which was also examined and described by Lamont and by a highly promising too early deceased North American astronomer, Mr. Mason, in the Memoirs of the American Philosophical Society, Vol. vii. p. 177); a nebula with six or eight nuclei (Cape Obs. p. 19, Pl. iii. fig. 4); a comet-like tuft-shaped nebula in which the nebulous rays sometimes appear as if proceeding from a star of the 9th magnitude (Pl. vi. fig. 18, No. 2534 and 3688); a nebula resembling the shade profile of a bust (Pl. iv. fig. 4, No. 3075); a creviced opening inclosing a thread-like nebula (No. 3501, Pl. iv. fig. 2).—Outlines, § 883; Cape Obs. § 121.

([415]) p. 239.—Kosmos, Bd. iii. S. 185 (English edit. p. 127); Outlines, § 785.

([416]) p. 239.—Kosmos, Bd. i. S. 157 and 415, Note 83 (Engl. edit. p. 141, Note 113. Sir John Herschel, first edition of Treatise on Astronomy, 1833, in Lardner's Cabinet Cyclopædia, § 616; Littrow, Theoretische Astronomie, 1834, Th. ii. § 234.

([417]) p. 239.—See Edinburgh Review, Jan. 1848, p. 187; and Cape Obs. § 96 and 107. "A zone of nebulæ," says Sir John Herschel, "encircling the heavens, has so many interruptions, and is so faintly marked out through by far the greater part of the circumference, that its existence as such can be hardly more than suspected."

([418]) p. 240.—"There is, I think, no doubt," wrote Dr. Galle, "that the drawing which you have sent me (Opere di Galilei, Padova, 1744, T. ii. p. 14, No. 20) includes Orion's belt and sword, and therefore the star $\theta$; but from the obvious inaccuracy of the drawing, the three small stars in the sword, the middle one of which is $\theta$, and which to the unassisted eye appear to form a straight line, are difficult to find. I should think that you have pointed out the star $\iota$ correctly, and that the bright star to the right of it, or the star immediately above, is $\theta$." Galileo says expressly: "In primo integram Orionis constellationem pingere decreveram; verum, ab ingenti stellarum copia, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli." The attention given by Galileo to the constellation of Orion is the more remarkable, because the number of 400 stars which he thought he counted in about ten square degrees between the belt and the sword (Nelli, Vita di Galilei, Vol. i. p. 208) misled Lambert (Cosmolog. Briefe, 1760, S. 155) so long afterwards into the erroneous estimate of 1650000 stars in the whole firmament (Struve, Astr. stellaire, p. 14, and Note 16).

([419]) p. 240.—Kosmos, Bd. ii. S. 369 (Eng. ed. p. 328).

([420]) p. 241.—"Ex his autem tres illæ pene inter se contiguæ stellæ, cumque his aliæ quatuor, velut trans nebulam lucebant: ita ut spatium circa psas, qua forma hic conspicitur, multo illustrius appareret reliquo omni cælo; quod cum apprime serenum esset ac cerneretur nigerrimum, velut hiatu quodam interruptum videbatur, per quem in plagam magis lucidam esset prospectus. Idem vero in hanc usque diem nihil immutata facie sæpius atque eodem loco conspexi; adeo ut perpetuam illic sedem habere credibile sit hoc quidquid est portenti: cui certe simile aliud nusquam apud reliquas fixsas potui animadvertere. Nam cæteræ nebulosæ olim existimatæ, atque ipsa via lactea, perspicillo inspectæ, nullas nebulas habere comperiuntur, neque aliud esse quam plurium stellarum congeries et frequentia" (Christiani Hugenii Opera varia, Lugd. Bat. 1724, p. 540-541). The magnifying power employed by Huygens in his 23-foot refractor was estimated by himself at only one hundred times (p. 538). Are the "quatuor stellæ trans nebulam lucentes" the stars of the trapezium? The small and very rough drawing (Tab xlvii. fig. 4, phenomenon in Orione novum) represents only a group of three stars; and indeed near an indentation which might be taken for the Sinus magnus. Perhaps only the three stars of the trapezium which are between the 4th and 7th magnitudes are indicated. Dominique Cassini boasted that he was the first person who had seen the fourth star.

([421]) p. 241.—William Cranch Bond, in the Transactions of the American Academy of Arts and Sciences, new series, Vol. iii. p. 87-96.

([422]) p. 242.—Cape Observations, § 54-69, Pl. viii.; Outlines, § 837 and 885, Pl. iv. fig. 1.

([423]) p. 242.—Sir John Herschel, in the Memoirs of the Astron. Soc. Vol. ii. 1824, p. 487-495, Pl. vii. and viii. This latter drawing gives the nomenclature of the different regions of the nebula in Orion which has been examined by so many astronomers.

([424]) p. 242.—Delambre, Hist. de l'Astr. moderne, T. ii. p. 700. Cassini reckoned the appearance of this fourth star ("aggiunta della quarta stella alle tre contigue") among the alterations which he considered the nebula in Orion had undergone in his time.

([425]) p. 242.—"It is remarkable that within the area of the trapezium no nebula exists. The brighter portion of the nebula immediately adjacent to the trapezium, forming the square front of the head, is shown with the 18-inch reflector broken up into masses, whose mottled and curdling light evidently indicates, by a sort of granular texture, its consisting of stars; and

when examined under the great light of Lord Rosse's reflector, or the exquisite defining power of the great achromatic at Cambridge, U.S., is evidently perceived to consist of clustering stars. There can, therefore, be very little doubt as to the whole consisting of stars, too minute to be discerned individually, even with these powerful aids, but which become visible as points of light when closely adjacent in the more crowded parts" (Outlines, p. 609). W. C. Bond, who employed a 23-foot refractor, furnished with a 14-inch object glass, says: "There is a great diminution of light in the interior of the trapezium, but no suspicion of a star (Mem. of the Amer. Acad., new series, Vol. iii. p. 93).

([426]) p. 243.—Phil. Trans. for the year 1811, Vol. ci. p. 324.

([427]) p. 243.—Transact. of the Royal Soc. of Edinburgh, Vol. xvi. 1849, Part 4, p. 445.

([428]) p. 243.—Kosmos, Bd. iii. S. 251-254; Eng. ed. p. 171-174.

([429]) p. 243.—Cape Observations, § 70-90, Pl. ix.; Outlines, § 887, Pl. iv. fig. 2.

([430]) p. 244.—Kosmos, Bd. ii. S. 146; Eng. ed. p. 112.

([431]) p. 244.—Cape Observations, § 24, Pl. i. fig. 1, No. 3721 of the Cat.; Outlines, § 888.

([432]) p. 244.—Nebula in Cygnus; partially in R. A. $20^h$ $49^m$, N.P. D. 58° 27′ (Outlines, § 891). Compare Cat. of 1833, No. 2092, Pl. xi. fig. 34.

([433]) p. 245.—Compare the drawings in Pl. ii. fig. 2, with Pl. v. in the "Thoughts on some Important Points relating to the System of the World," 1846 (by Dr. Nichol, Professor of Astronomy at Glasgow), p. 22. Sir John Herschel, in his Outlines of Astronomy, p. 607, says—"Lord Rosse describes and figures this nebula as resolved into numerous stars *with intermixed nebula.*"

([434]) p. 245.—Kosmos, Bd. i. S. 157 and 415, Anm. 81 (Eng. ed. p. 141 and xxxviii.), where the nebula No. 1622 is called a "brother-system."

([435]) p. 245.—Report of the 15th Meeting of the British Association for the Advancement of Science, Notices, p. 4; Nichol, Thoughts, p. 23 (compare Pl. ii. fig. 1 with Pl. vi.) In the Outlines, § 882, it is said, "the whole, if not clearly resolved into stars, has a *resolvable* character which evidently indicates its composition."

([436]) p. 246.—Kosmos, Bd. i. S. 88 and 387 (Anm. 2); Eng. ed. p. 76 and Note 32.

([437]) p. 246.—Lacaille, in the Mém. de l'Acad. année 1755, p. 195. It is objectionable to apply, as Horner and Littrow have done, the name of "Magellanic Spots or Cape-clouds" to the coal-sacks.

(438) p. 246.—Kosmos, Bd. ii. S. 329 and 485 (Anm. 6); Eng. ed. p. 289, xcv. Note 446.

(439) p. 247.—Ideler, Untersuchungen über den Ursprung und die Bedeutung der Sternnamen (Investigations respecting the Origin and Signification of the Names of Stars), 1809, S. xlix. and 262. The name Abdurrahman Sufi is abbreviated by Ulugh Beg from AbdurrahmanEbn-Omar Ebn-Mohammed Ebn-Sahl Abu'l-Hassan el-Sufi el-Razi. Ulugh Beg, who, like Nassir-eddin, corrected the star-positions of Ptolemy by his own observations (1437), owns to having borrowed the positions of 27 more southern stars, not visible at Samarcand, from Abdurrahman Sufi.

(440) p. 248.—Compare my geographical inquiries respecting the discovery of the south point of Africa, and the statements of Cardinal Zurla and Count Baldelli, in the Examen. crit. de l'hist. de la Géogr. aux 15ème et 16ème Siécles, T. i. p. 229-348. It is a curious fact that the discovery of the Cape of Good Hope, which Martin Behaim calls Terra Fragosa, not Cabo Tormentoso, was made by Diaz in coming from the *eastward* (from Algoa Bay, in 33° 47′ S. lat., more than 7° 18′ east of Table Bay). Lichtenstein im Vaterlandischen Museum, Hamburg, 1810, S. 372-389.

(441) p. 249.—The important, and not sufficiently noticed, discovery of the South point of the New Continent, in S. lat. 55° (very characteristically indicated in Urdaneta's journal by the words "acabamiento de tierra," the ceasing or terminating of the land), belongs to Francisco de Hoces, who commanded one of the ships of Loaysa's Expedition in 1525. He probably saw a part of Tierra del Fuego west of Staaten Island; for Cape Horn is, according to Fitz-Roy, in 55° 58′ 41″. Compare Navarrete, Viages y descubrim. de los Españoles, T. v. p. 28 and 404.

(442) p. 250.—Humboldt, Examen crit. T. iv. p. 205, 295-316; T. v. p. 225-229 and 235 (Ideler, Sternnamen, S. 346).

(443) p. 250.—Petrus Martyr Angl., Oceanica, Dec. III. lib. i. p. 217. I can show, from the numerical data in Dec. II. lib. x. p. 204, and Dec. III. lib. x. p. 232, that the part of the "Oceanica" in which the Magellanic Clouds are mentioned was written between 1514 and 1516; therefore, immediately after the Expedition of Juan Diaz de Solis to the Rio de la Plata (then called "Rio de Solis, una mar dulce"). The latitude assigned is much too high.

(444) p. 251.—Kosmos, Bd. ii. S. 329, Bd. iii. S. 151 and 175; Eng. ed. Vol. ii. p. 290, Vol. iii. p. 94 and 117.

(445) p. 252.—Kosmos, Bd. i. S. 88 and 387, Anm. 2; Eng. ed. p. 76 and xv. Note 32. Compare, in Cape Observations, 143-164, the Magellanic Clouds as they appear to the naked eye, Pl. vii.; telescopic analysis of the

Nubecula major, Pl. x.; and the Nebula of the Dorado represented separately, Pl. ii. fig 4 (§ 20-23): Outlines, § 892-896, Pl. v. fig. 1; and James Dunlop, in the Phil. Trans. for 1828, Part i. p. 147-151. So erroneous were the views of early observers, that the Jesuit Fontaney, an observer highly esteemed by Dominique Cassini, and to whom many valuable astronomical observations from India and China are owing, wrote, as late as 1685—"Le grand et le petit Nuages sont deux choses singulières. Ils ne paroissent aucunement un amas d'étoiles comme Præsepe Cancri, ni même une lueur sombre comme la nébuleuse d'Andromède. On n'y voit presque rien avec de très grandes lunettes, quoique sans ce secours on les voye fort blancs, particulièrement le grand Nuage" (Lettre du Père de Fontaney au Père de la Chaise, Confesseur du Roi, in the Lettres édifiantes, Recueil vii. 1703, p. 78; and Hist. de l'Acad. des Sciences dep. 1686-1699, T. ii. Paris, 1733, p. 19).—I have followed Sir John Herschel exclusively in the description of the Magellanic Clouds given in the text.

(446) p. 252.—Kosmos, Bd. iii. S. 183 and 212 (Anm. 85); Eng. ed. p. 125 and lxiv. Note 251.

(447) p. 252.—The same, S. 180 and 211 (Anm. 75); Eng. ed. p. 122 and lxiii. Note 241.

(448) p. 254.—Compare, in Cape Observations, § 20-23 and 133, the fine drawing, Pl. ii. fig. 4, and a small special map in the graphical analysis, Pl. x.; as well as Outlines, § 896, Pl. v. fig. 1.

(449) p. 255.—Kosmos, Bd. ii. S. 328 and 485 (Anm. 5); Eng. ed. p. 289 and xcv. Note 445.

(450) p. 255.—Mem. de l'Acad. des Sciences, dep. 1666 jusqu'à 1699, T. vii. Partie 2 (Paris, 1729), p. 206.

(451) p. 255.—Letter to Olbers from St. Catherine's (Jan. 1804), in Zach's Monatl. Correspondenz zur Beförd. der Erd- und Himmels-kunde, Bd. x. S. 240. (Respecting Feuillée's observation, and the rough drawing of the black patch in the Southern Cross, compare, also, Zach's Correspondenz, Bd. xv. 1807, S. 388-391).

(452) p. 256.—Cape Observations, Pl. xiii.

(453) p. 256.—Outlines of Astronomy, p. 531.

(454) p. 256.—Cape Observations, p. 384, No. 3407 of the catalogue of nebulæ and star-clusters. (Compare Dunlop, in the Phil. Trans. for 1828, p. 149, and No. 272 of his catalogue).

(456) p. 257.—"Cette apparence d'un noir foncé dans la partie orientale de la Croix du Sud, qui frappe la vue de tous ceux qui regardent le ciel austral,

est causée par la vivacité de la blancheur de la voie lactée qui renferme l'espace noir et l'entoure de tous cotés."—Lacaille, in the Mém. de l'Acad. des Sciences, année 1755 (Paris, 1761), p. 199.

(457) p. 257.—Bd. i. S. 159 and 415 (Anm. 87); Eng. ed. p. 143 and xxxviii. Note 117.

(458) p. 257.—"When we see," says Sir John Herschel, "in the Coal-sack (near α Crucis) a sharply-defined oval space free from stars, it would seem much less probable that a conical or *tubular* hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side. . . . " (Outlines, § 792, p. 532; Lettre de Mr. Hooke à Mr. Auzout, in the Mém. de l'Académie, 1666-1699, T. viii. Partie 2, p. 30 and 73).

(459) p. 258.—Kosmos, Bd. i. S. 161; Eng. ed. p. 145.

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(460) p. 261.—Compare what was said in an earlier volume, where distances of Uranus were employed as units of measure, that planet being the outermost member of the planetary system as then known to us (Kosmos Bd. i. S. 116, 153, and 415, Anm. 76; Eng. ed. p. 102, 103, 137, 138, and Note 106). Taking the distance of Neptune from the Sun at 30·04 distances of the Earth from the Sun, the distance of α Centauri from the Sun will be 7523 distances of Neptune, the parallax of the star being assumed to be 0″.9128 (Kosmos, Bd. iii. S. 274, Eng. ed. p. 189); and yet the distance of 61 Cygni is almost twice and a half, and that of Sirius (taking its parallax at 0″·230) four times as great as that of α Centauri. A "distance of Neptune" is about 621 German, (2484 English) millions of geographical miles; and the distance of Uranus from the Sun, according to Hansen, is 396½ (Eng. 1586) millions of such miles. According to Galle, the distance of Sirius, taking Henderson's parallax, is 896800 semi-diameters of the Earth's orbit = 18547000 (74188000 Eng.) millions of geographical miles—a distance which light requires 14 years to traverse. The aphelion of the comet of 1680 is 44 distances of Uranus, or 28 distances of Neptune, from the Sun. According to the above assumptions, the solar distance of the star α Centauri is almost 270 times greater than this cometary aphelion, which is here regarded as the minimum of the necessarily very uncertain estimation of the radius of the solar domain (Kosmos, Bd. iii. S. 294, Eng. ed. p. 204). In

this class of numerical data, the advantage gained by employing very great distances in space as our units of measure is, that we are thus enabled to express the results with a less enormous array of figures.

(461) p. 262.—On the appearance and disappearance of new stars, see Kosmos, Bd. iii. S. 215-233; Eng. ed. p. 132-152.

(462) p. 267.—I have printed, in an earlier volume (Kosmos, Bd. ii. S. 347 and 499, Anm. 25; Eng. ed. p. 307 and cvi. Note 465), the passage in the 10th chapter of the first book "de Revolut.," imitated from the Somnium Scipionis.

(463) p. 267.—Theonis Smyrnæi Platonici Liber de Astronomia, ed. H. Martin, 1849, p. 182 and 298: *τῆs ἐμψυχιας μέσον τὸ περι τὸν ἥλιον, οιονει καρδιαν ὄντα του παντὸs, ὅθεν φέρουσιν αυτôυ καὶ τὴν ψυχὴν ἀρξαμένην διὰ παντὸs ἥκειν τοῦ σώματοs τεταμένην ἀπὸ τῶν περάτων.* (This new edition is worthy of notice, in reference to the peripatetic opinions of Adrastus, and many platonic opinions of Dercyllides.

(464) p. 269.—Hansen, in Schumacher's Jahrbuch für 1837, S. 65-141.

(465) p. 271.—"D'après l'état actuel de nos connaissances astronomiques le Soleil se compose: 1° d'un globe central à peu près obscur; 2° d'une immense couche de nuages qui est suspendue à une certaine distance de ce globe et l'enveloppe de toutes parts; 3° d'une *photosphère;* en d'autres termes, d'une sphère resplendissante qui enveloppe la couche nuageuse, comme celle-ci, à son tour, enveloppe le noyau obscur. L'éclipse totale du 8 Juillet 1842 nous a mis sur la trace d'une troisième enveloppe, située au-dessus de la *photosphère,* et formée de nuages obscurs ou faiblement lumineux.—Ce sont les *nuages* de la troisième enveloppe solaire, situés en apparence pendant l'éclipse totale, sur le contour de l'astre ou un peu en dehors, qui ont donné lieu à ces singulières proéminences rougeâtres qui en 1842 ont si vivement excité l'attention du monde savant" (Arago, in the Annuaire du Bureau des Longitudes pour l'an 1846, p. 464 and 471). Sir John Herschel, in his Outlines of Astronomy, published in 1849 (p. 234, § 395), also assumes—"above the luminous surface of the Sun, and the region in which the spots reside, the existence of a gaseous atmosphere having a somewhat imperfect transparency."

(466) p. 272.—It is proper to give first in the original the passages which are alluded to in the text, and to which my own attention was called by an instructive memoir by Dr. Clemens ("Giordano Bruno und Nicolaus von Cusa," 1847, S. 101). The Cardinal Nicolaus of Cusa (the family name was Khrypffs—*i. e.* écrevisse, craw-fish), a native of Cues, on the Moselle,

says, in the 12th chapter of the second book of a treatise which enjoyed great celebrity at the time, "de docta Ignorantia" (Nicolai de Cusa, Opera, ed. Basil. 1565, p. 39): "neque color nigredinis est argumentum vilitatis Terræ; nam in Sole, si quis esset, non appareret illa claritas quæ nobis: considerato enim corpore Solis, tunc habet quandam quasi terram centraliorem, et quandam luciditatem quasi ignilem circumferentialem, et in medio quasi aqueam nubem et ærem clariorem, quem admodum terra ista sua elementa." On the margin is written "Paradoxa" and "Hypni:" the latter word must, there fore, doubtless signify here also "dreams" (ἐνύπνια)—some hazardous specuation. Again, in a figurative comparison occurring in a long writing—Exercitationes ex Sermonibus Cardinalis (Opera, p. 579)—I find "Sicut in Sole considerari potest natura corporalis, et illa de se non est magnæ virtutis" (notwithstanding mass-attraction or gravitation!) "et non potest virtutem suam aliis corporibus communicare, quia non est radiosa. Et alia natura lucida illi unita, ita quod Sol ex unione utriusque naturæ habet virtutem, quæ sufficit huic sensibili mundo, ad vitam innovandam in vegetabilibus et animalibus, in elementis et mineralibus, per suam influentiam radiosam. Sic de Christo, qui est Sol justitiæ . . . ." Dr. Clemens thinks that all this be something more than a happy conjectural anticipation. It appears to him "simply impossible that in the parts of the passage quoted (*considerato corpore Solis;* in Sole considerari potest . . . ) Cusa could have appealed to experience, unless there had been some tolerably accurate observation of the solar spots, both of their darker parts and of the penumbra." He conjectures "that the philosophers of modern science had been anticipated in some of the results obtained by them, and that the Cardinal's views may have been influenced by discoveries which are generally, but erroneously, supposed to have been first made at a later period." It is certainly not only possible, but even very probable, that in districts where the sun is partially veiled for several months—as during the continuance of the "garua" on the coast of Peru—solar spots may have been seen even by uncivilised men with the naked eye; but we have no accounts from any travellers of such a circumstance having attracted attention, or of the spots of the sun having ever been interwoven in the mythology of worshippers of that luminary. The mere, and very rare, sight with the naked eye of a solar spot on the sun's disk, when either low down near the horizon, or covered with a thin veil of mist, and appearing white, red, or perhaps even of a greenish hue, would, I think, never have led even men exercised in intellectual thought to conjecture the existence of several successive coverings enveloping the dark body of the sun.

If Cardinal Cusa had known anything about solar spots, he would surely not have failed to introduce the "maculæ Solis" in some of the numerous comparisons which he so much delighted in drawing between physical and spiritual things. Let us only remember the vehement debates excited in the beginning of the 17th century, immediately after the invention of the telescope, by the discoveries of Fabricius and of Galileo. I have recalled in an earlier volume (Kosmos, Bd. ii. S. 503, Anm. 33; Eng. ed. p. cix. Note 473) the obscurely expressed astronomical representations of the Cardinal, who died in 1464, nine years, therefore, before the birth of Copernicus. The remarkable passage, "jam nobis manifestum est Terram in veritate moveri," is in lib. ii. cap. 12, de docta Ignorantia. According to Cusa, all things are in movement in every part of celestial space; we find no star which does not describe a circle. "Terra non potest esse fixa, sed movetur ut aliæ stellæ." He does not, however, suppose the Earth to revolve round the Sun, but the Earth and Sun to revolve "round the ever-changing poles of the Universe." Cusa, therefore, was not a Copernican, as is shown by this fragment, written by him with his own hand in 1444, and discovered by Dr. Clemens in the hospital at Cues.

([467]) p. 272.—Kosmos, Bd. ii. S. 360-362 and 511-512, Anm. 49-53; Eng. ed. p. 319-321 and cxvi.-cxvii. Notes 489-493.

([468]) p. 272.—"*Borbonia Sidera*, id est planetæ qui Solis lumina circumvolitant motu proprio et regulari, falso hactenus ab helioscopis Maculæ Solis nuncupati, ex novis observationibus Joannis Tarde, 1620.—*Austriaca Sidera* heliocyclica astronomicis hypothesibus illigata opera Caroli Malapertii Belgæ Montensis e Societate Jesu, 1633." The last-mentioned memoir has at least the merit of furnishing observations of a series of solar spots between 1618 and 1626. These are, however, the same years as those for which Scheiner published his own observations at Rome in his "Rosa Ursina." The Canon Tarde believed in the transit of small planets, because he deemed it impossible to ascribe such imperfections to the "eye of the World"—l'œil du Monde ne peut avoir des ophthalmies!" It is indeed surprising that, twenty years after Tarde's account of his Borbonia Sidera, Gascoigne, to whom the art of observation is so much indebted (Kosmos, Bd. iii. S. 76; Eng. ed. p. 59), should still have attributed the solar spots to the conjunction of numerous planetary, almost transparent, bodies revolving round the sun in great proximity to it. He supposed several of these, superposed upon each other, to be the cause of the dark shaded places. (Phil Trans., Vol. xxvii. 1710-1712, p. 282-290, letter from William Crabtrie, August 1640.)

(469) p. 272.—Arago "sur les moyens d'observer les taches solaires," in the Annuaire for 1842, p. 476-479. (Delambre, Hist. de l'Astronomie du Moyen Age, p. 394, as well as Hist. de l'Astr. moderne, T. i. p. 681.)

(470) p. 273.—Mémoires pour servir à l'Histoire des Sciences, par Mr. le Comte de Cassini, 1810, p. 242; Delambre, Hist. de l'Astr. mod. T. ii. p. 694. Although Cassini, as early as 1671, and La Hire in 1700, declared the body of the Sun to be dark, yet estimable elementary works on astronomy still continue to ascribe the first idea of this hypothesis to the meritoriou astronomer Lalande. Lalande himself, in the edition of his Astronomy pub lished in 1792, T. iii. § 3240, as well as in the first edition of 1764, T. i § 2515, merely remains true to La Hire's earlier expressed opinion—viz "que les taches sont les éminences de la masse solide et opaque du Soleil recouverte communément (en entier) par le fluide igné." Between 1769 and 1774, Alexander Wilson formed the first just view of a funnel-shaped opening in the photosphere.

(471) p. 273.—Alexander Wilson, Observations on the Solar Spots, in the Phil Trans. Vol. lxiv. 1774, Part 1, p. 6-13, Tab. i.—"I found that the umbra, which before was equally broad all round the nucleus, appeared much contracted *on that part which lay towards the centre of the disk,* whilst the other parts of it remained nearly of the former dimensions. I perceived that the shady zone or umbra which surrounded the nucleus might be nothing else but the shelving sides of the luminous matter of the sun." Compare, also, Arago, in the Annuaire for 1842, p. 506.

(472) p. 274.—Bode, in the Beschäftigungen der Berlinischen Gesellschaft Naturforschender Freunde, Bd. ii. 1776, S. 237-241 and 249.

(473) p. 277.—William Herschel, in the Philosophical Transactions of the Royal Society for 1801, Part 2. p. 310-316.

(474) p. 278.—An official notice of a high price of corn occurring in connection with obscuration of the sun for several months, is referred to in the historic fragments of the elder Cato. "Luminis caligo" and "defectus Solis" are expressions which, when employed by Roman writers, do not by any means signify on all occasions an eclipse of the sun; they have, for instance, no such meaning in the accounts of the long-continued dimness of the sun which is said to have followed the death of Cæsar. Thus we find in Aulus Gellius, in Noct. Att. ii. 28—"Verba Catonis in originum quarto hæc sunt: non libet scribere, quod in tabula apud Pontificem maximum est, quotiens anona cara, quotiens lunæ an solis lumini caligo, aut quid obstiterit."

(4) p. 278.—Gautier, Recherches relatives à l'influence que le nombre des

taches solaires exerce sur les températures terrestres, in the Bibliothèque Universelle de Genève, Nouv. Série, T. li. 1844, p. 327-335.

(476) p. 278.—Arago, in the Annuaire pour 1846, p. 271-438.

(477) p. 278.—The same, p. 440-447.

(478) p. 279.—This is the whitish shining appearance which was also seen in the solar eclipse of the 15th of May, 1836, and of which even then the great Königsberg astronomer said very correctly, that "when the moon's disk completely covered the sun there still remained visible a luminous ring of the solar atmosphere" (Bessel, in Schum. Astr. Nachr. No. 320).

(479) p. 279.—"Si nous examinions de plus près l'explication d'après laquelle les protubérances rougeâtres seraient assimilées à des nuages (de la troisième enveloppe), nous ne trouverions aucun principe de physique qui nous empêchât d'admettre que des masses nuageuses de 25 à 30000 lieues de long flottent dans l'atmosphère du Soleil ; que ces masses, comme certains nuages de l'atmosphère terrestre, ont des contours arrêtès, qu'elles affectent, çà et là, des formes très tourmentées, même des formes en surplomb ; que la lumière solaire (la photosphère) les colore en rouge.—Si cette troisième enveloppe existe, elle donnera peut-être la clef de quelques unes des grandes et deplorables anomalies que l'on remarque dans le cours des saisons" (Arago, in the Annuaire for 1846, p. 460 and 467).

(480) p. 280.—"Tout ce qui affaiblira sensiblement l'intensité éclairante de la portion de l'atmosphère terrestre qui parait entourer et toucher le contour circulaire du Soleil, pourra contribuer à rendre les proéminences rougeâtres visibles. Il est donc permis d'espérer qu'un astronome exercé, établi au sommet d'une très haute montagne, pourrait y observer regulièrement les *nuages de la troisième enveloppe solaire*, situés en apparence sur le contour de l'astre *ou un peu en dehors ;* déterminer ce qu'ils ont de permanent et de variable, noter les périodes de disparition et de réapparition . . . ." (Arago, Annuaire for 1846, p. 471).

(481) p. 282.—Although it is undeniably possible that particular individuals among the Greeks and Romans may have seen large solar spots with the naked eye, yet it appears certain that such isolated observations, supposing them to have taken place, never led Greek or Roman writers to allude to those phenomena in any work which has come down to us. The passages in Theophrast. de Signis, iv. 1, p. 797,—Aratus Diosem, v. 90-92,—and Proclus, Paraphr. ii. 14, in which the younger Ideler (Meteorol. Veterum, p. 201, and Commentary on Aristot. Meteor. T. i. p. 374) thinks he perceives a men-

tion of solar spots—merely say that the sun's disk, which indicates good weather, shows no diversity of surface, nothing that marks it (μηδέ τι σῆμα φεροι), but rather perfect uniformity. The σῆμα, or chequered surface, is, moreover, expressly attributed to light cloud, belonging to the vapours of our atmosphere (the Scholiast to Aratus says, the "thickness of the air"): hence it is always the morning or the evening sun which is referred to, and which, quite independently of true solar spots, may certainly serve as *diaphanometers*, and are still regarded, both by sailors and agriculturists, according to an opinion by no means worthy of being despised, as affording useful indications of approaching changes of weather. The sun's disk, when near or on the horizon, is seen through the lowest atmospheric strata. Of the large solar spots which were seen by the naked eye in the years 807 and 840, and erroneously supposed to be transits of Mercury and Venus, the first was recorded in the great historic collection of Justus Reuberus, Veteres Scriptores (1726), in the part entitled Annales Regum Francorum Pipini Karoli Magni et Ludovici a quodam ejus ætatis Astronomo, Ludovici regis domestico, conscripti, p. 58. The authorship of these Annals was first attributed to a Benedictine monk (p. 28), and afterwards, and more correctly, to the celebrated Eginhard (Einhard, Charlemagne's private secretary): see Annales Einhardi, in Pertz's Monumenta Germaniæ historica, Script. T. i. p. 194. The passage referred to is the following:—"DCCCVII. stella Mercurii xvi. Kal. April. visa est in Sole qualis parva macula nigra, paululum superius medio centro ejusdem sideris, *quæ a nobis* octo dies conspicata est; sed quando primum intravit vel exivit, nubibus impedientibus, minime notare potuimus." The passage respecting the supposed transit of Venus mentioned by Arabian astronomers, is given by Simon Assemannus in the Introduction to the "Globus cœlestis Cufico-Arabicus Veliterni Musei Borgiani," 1790, p. xxxviii., and is as follows:—"Anno Hegyræ 225, regnante Almootasemo Chalifa, visa est in Sole prope medium nigra quædam macula, idque feria tertia die decima nona Mensis Regebi . . . ." It was believed to be the planet, and that *the same* macula nigra (therefore with interruptions of 12 or 13 days) was seen for 91 days. Soon afterwards Motassem died.—I subjoin 17 instances, taken from a larger number collected by me, of historical or traditional accounts of suddenly-occurring diminutions or obscurations of the light of day:—

Anno 45 B.C., at the time of the death of Julius Cæsar, after which the sun was for a whole year paler, and gave less heat than usual. so

that the air was thick; cold, and misty, and the fruits of the earth failed (Plutarch, in Jul. Cæs. cap. 87, Dio Cass. xliv. Virg. Georg. i. 466).

A.D. 33, at the time of our Saviour's crucifixion. "From the sixth hour there was darkness over all the land unto the ninth hour" (Matth. xxvii. 45); and in the parallel passage in St. Luke, "the sun was darkened" (Luke, xxiii. 45). Eusebius adduces, in explanation and confirmation, an eclipse of the Sun in the 202d Olympiad, mentioned by Phlegon, of Tralles, a writer of chronicles (Ideler, Handbuch der mathem. der Chronologie, Bd. ii. S. 147). But Wurm has shown that the eclipse belonging to this Olympiad, and which was visible over all Asia Minor, took place on the 24th of November, 29 years after the birth of Christ, or between three or four years earlier. The Crucifixion was at the time of the Passover, 14 Nisan (Ideler, Bd. i. S. 515-520), which was always celebrated at the time of the full moon. The sun cannot, therefore, have been eclipsed by the moon for three hours. The Jesuit Scheiner was inclined to attribute the diminution of light to a group of large solar spots.

358.—On the 22d of August, an obscuration of two hours in length, *previous* to the terrible earthquake of Nicomedia, which also destroyed many other towns in Macedonia and Pontus. The darkness lasted between two and three hours: "nec contigua vel adposita cernebantur." Ammian. Marcell. xvii. 7.

360.—In all the Eastern provinces of the Roman Empire (per Eoostractus) there was "caligo a primo auroræ exortu adusque meridiem" (Ammian. Marcell. xx. 3), but stars were seen; therefore it could not have been caused by showers of ashes; nor, from the long duration of the phenomenon, could it have been the effect of a total solar eclipse, to which the historian attributes it: "Cum lux cœlestis operiretur, e mundi conspectu penitus luce abrepta, defecisse diutius solem pavidæ mentes hominum æstimabant: primo attenuatum in lunæ corniculantis effigiem, deinde in speciem auctum semenstrem, posteaque in integrum restitutum. Quod alias non evenit ita perspicue, nisi cum post inæquales cursus intermenstruum lunæ ad idem revocatur." The description is quite that of a true solar eclipse; but what is to be done with the length of time and "caligo" in all the Eastern provinces?

409.—When Alaric appeared before Rome: the darkness such that

stars were seen in the day-time. Schnurrer, Chronik der Seuchen, Th. i. S. 113.

536.—"Justinianus I. Cæsar imperavit annos triginta octo (527 to 565). Anno imperii nono deliquium lucis passus est Sol, quod annum integrum et duos amplius menses duravit, adeo ut parum admodum de luce ipsius appareret; dixeruntque homines Soli aliquid accidisse, quod nunquam ab eo recederet." Gregorius Abu'l-Faragius, Supplementum Historiæ Dynastiarum, ed. Edw. Pocock, 1663, p. 94. This seems to have been a phenomenon very similar to that of 1783, to which the name of "Hohenrauch" has been given, but for such phænomena no general satisfactory explanation has been assigned.

567.—Justinus II. annos 13 imperavit (565-578). Anno imperii ipsius secundo apparuit in cœlo ignis flammans juxta polum arcticum qui annum integrum permansit; obtexeruntque tenebræ mundum ab hora diei nona noctem usque, adeo ut nemo quicquam videret; deciditque ex ære quoddam pulveri minuto et cineri simile. Abu'l-Farag. l. c. p. 95. For a year continual Aurora, afterwards darkness, and showers of what we call "trade-wind dust" (?).

626.—According to Abu'l-Farag. (Hist. Dynast. p. 94 and 99), half the sun's disk continued obscured for eight months.

733.—A year after the Arabs had been driven back beyond the Pyrenees, as the result of the battle of Tours, the sun was darkened on the 19th of August in a terrifying manner. Schnurrer, Chron. Th. i. S. 164.

807.—A spot on the sun which was taken for Mercury. Reuber, Vet. Script. p. 58 (see above, p. xcviii.)

840.—From the 28th of May to the 26th of August (Assemani reckons May 839), the so-called transit of Venus over the sun's disk. See above, p. xcviii. (The Caliph Al-Motassem reigned from 834 to 841, when he was succeeded by Haroun-el-Vatek, the ninth Caliph.)

934.—In the valuable History of Portugal by Faria y Sousa, 1730, p. 147, I find—"En Portugal se vió sin luz la tierra por dos meses. Avia el Sol perdido su splendor." An opening in the sky then seemed to take place "por fractura," with many flashes of lightning, and the full blaze of sunshine was then suddenly restored.

1091.—On the 21st of September a darkening of the sun took place

which lasted three hours, and after the obscuration had passed away the solar disk remained of a peculiar colour. "Fuit eclipsis Solis 11 Kal. Octob. fere tres horas: Sol circa meridiem dire nigrescebat." Martin Crusius, Annales Svevici, Francof. 1595, T. i. p. 279; Schnurrer, Th. i. S. 219.

1096.—On the 3d of May solar spots were seen with the naked eye: Signum in Sole apparuit V. Non Marcii feria secunda incipientis quadragesimæ. Joh. Staindelii, presbyteri Pataviensis, Chronicon generale, in Œfelii Rerum Boicarum Scriptoris, T. i. 1763, p. 485.

1206.—On the last day of February, according to Joaquin de Villaba (Epidemiologia Española Madr. 1803, T. i. p. 30), there was complete darkness for 6 hours: "el dia ultimo del mes de Febrero hubo un eclipse de sol que duró seis horas con tanta obscuridad como si fuera media noche. Siguiéron á este fenomeno abundantes y continuas lluvias." Schnurrer, Th. i. S. 258 and 265, speaks of an almost similar phenomenon in June 1191.

1241.—Five months after the Mongol battle of Leignitz: "obscuratus est Sol (in quibusdam locis?), et factæ sunt tenebræ, *ita* ut stellæ viderentur in cœlo, circa festum S. Michaelis hora nona." Chronicon Claustro-Neoburgense (of the Neuburg Convent near Vienna, containing the years 218 to 1348 A.D.), in Pez, Scriptores rerum Austriacarum," Lips. 1721, T. i. p. 458.

1547.—The 23d, 24th, and 25th of April,—therefore a day before and a day after, as well as the actual day, of the battle of Mühlbach, in which the Prince Elector John Frederic was taken. Kepler says, (in Paralipom. ad Vitellium, quibus Astronomiæ pars optica traditur, 1604, p. 259)—"refert Gemma, pater et filius, anno 1547 ante conflictum Caroli V. cum Saxoniæ Duce Solem per tres dies ceu sanguine perfusum comparuisse, ut etiam stellæ pleræque in meridie conspicerentur." (So, also, Kepler, de Stella nova in Serpentario, p. 13). Great doubt exists as to the cause: "Solis lumen ob causas quasdam sublimes hebetari......" perhaps there may have been materia cometica latius sparsa. The cause cannot have been in our atmosphere, because stars were seen at noon." Schnurrer (Chronik der Seuchen, Th. ii. S. 93) is inclined to believe, notwithstanding the visibility of stars, that it was an "Hohenrauch," or a foreign admixture in the atmosphere, because the Emperor Charles V. complained before the battle

that "semper se nebulæ densitate infestari, quoties sibi cum hoste pugnandum sit" (Lambert, Hortens. de bello german. lib. vi. p. 182).

(482) p. 283.—Horrebow (Basis Astronomiæ, 1735, § 226) already uses the same expression. The solar light is, according to him, "An *Aurora borealis*, produced by active *magnetic forces continually* in operation in the *Sun's atmosphere*." (See Hanow, in Joh. Dan. Titius, gemeinnützige Abhandlungen über natürliche Dinge, 1768, S. 102.)

(483) p. 286.—Arago, in the Mémoires des Sciences mathém. et phys. d l'Institut de France, Année 1811, Partie i. p. 118; Mathieu, in Delambre Hist. de l'Astr. au 18ème Siècle, p. 351 and 652; Fourier, Eloge de William Herschel, in the Mém. de l'Institut, T. vi. Année 1823 (Par. 1827), p. lxxii. The result of an ingenious experiment of Forbes during a solar eclipse in 1836 is also remarkable, and evidences great homogeneity in the nature of the light which emanates from the centre and from the margin of the Sun's disc: a spectrum formed exclusively by rays either from the margin or limb was found perfectly identical, in respect to the number and position of the dark lines traversing it, with the spectrum which is formed by the whole of the rays. If rays of a certain refrangibility are wanting in the solar light, it is not, as Sir David Brewster conjectures, because they are lost in the Sun's atmosphere; since the marginal rays which traverse a much thicker stratum produce the same dark lines. (Forbes, in the Comptes rendus, T. ii. 1836, p. 576.) I conclude this note by subjoining all that I collected on this subject, in 1847, from Arago's manuscripts:—

"Des phénomènes de la polarisation colorée donnent la certitude que le bord du Soleil a la même intensité de lumière que le centre; car en plaçant dans la polariscope un segment du bord sur un segment du centre, j'obtiens (comme effet complémentaire du rouge et du bleu) un blanc pur. Dans un corps solide (dans une boule de fer chauffée au rouge) le même angle de vision embrasse une plus grande étendue au bord qu'au centre, selon la proportion du Cosinus de l'angle; mais dans la même proportion aussi le plus grand nombre de points matériels émettent une lumière plus faible *en raison de leur obliquité*. Le rapport de l'angle est naturellement le même pour une sphère gazeuse; mais l'obliquité ne produisant pas dans les gaz le même effet de diminution que dans les corps solides, le bord de la sphère gazeuse serait plus lumineux que le centre. Ce que nous appellons le disque lumineux du Soleil, est la photosphère gazeuse, comme je l'ai prouvé par le manque absolu de traces de polarisation sur le bord du disque. Pour expliquer donc *l'égalité d'intensité* du bord et du centre indiquée par le polariscope, il faut admettre

une enveloppe extérieure qui diminue (éteint) moins la lumière qui vient du centre que les rayons qui viennent sur le long trajet du bord à l'œil. Cette enveloppe extérieure forme la couronne blanchâtre dans les éclipses totales du Soleil. — La lumière qui émane des corps solides et liquides incandescens, est partiellement polarisée quand les rayons observés forment avec la surface de sortie, un angle d'un petit nombre de degrés; mais il n'y a aucune trace sensible de polarisation lorsqu'on regarde de la même manière dans le polariscope des gaz enflammés. Cette expérience demontre que la lumière solaire ne sort pas d'une masse solide ou liquide incandescente. La lumière ne s'engendre pas uniquement à la surface des corps ; une portion naît dans leur substance même, cette substance fût-elle du platine. Ce n'est donc pas la décomposition de l'oxygène ambiant qui donne la lumière. L'émission de lumière polarisée par le fer liquide est un effet de réfraction au passage vers un moyen d'une moindre densité. Partout où il y a réfraction, il y a production d'un peu de lumière polarisée. Les gaz n'en donnent pas, parceque leur couches n'ont pas assez de densité. La lune suivie pendant le cours d'une lunaison entière offre des effets de polarisation, excepté à l'époque de la pleine lune et des jours qui en approchent beaucoup. La lumière solaire trouve, surtout dans les premiers et derniers quartiers, à la surface inégale (montagneuse) de notre satellite, des inclinaisons de plans convenables pour produire la polarisation par réflexion."

([484]) p. 286.—Sir John Herschel, Astron. Observ. made at the Cape of Good Hope, § 425, p. 434; Outlines of Astr. § 395, p. 234. Compare Fizeau and Foucault, in the Comptes rendus de l'Acad. des Sciences, T. xviii. 1844, p. 860. It is sufficiently remarkable that Giordano Bruno, who ascended the scaffold eight years before the invention of the telescope, and eleven years before the discovery of the solar spots, believed already in the rotation of the Sun around its axis. On the other hand, he considered the light of the centre of the Sun's disk to be inferior in intensity to that of the margin. He imagined, by some effect of optical illusion, that he saw the Sun's disk turn, and its whirling edges expand and contract. (Jordano Bruno, par Christian Bartholmèss, T. ii. 1847, p. 367.)

([485]) p. 287.—Fizeau and Foucault, Recherches sur l'intensité de la lumière émise par le charbon dans l'expérience de Davy, in the Comptes rendus, T. xviii. 1844, p. 753.—"The most intensely ignited solids (ignited quicklime in Drummond's oxy-hydrogen lamp) appear only as *black spots* on the disk of the Sun when held between it and the eye." (Outlines, p. 326: Kosmos, Bd. ii. S. 361; English Ed. p. 321.)

([486]) p. 287.—Compare Arago's comments on Galileo's letters to Marcus Welser, and his optical explanations and remarks on the influence of the diffused solar light reflected from the strata of the atmosphere, which covers as it were with a veil of light objects seen on the face of the heavens in the field of a telescope. (Annuaire du Bureau des Longitudes for 1842, p. 482—487.)

([487]) p. 288.—Mädler, Astr. S. 81.

([488]) p. 288.—Philos. Magazine, Ser. iii. Vol. 28, p. 230; and Poggend. Annalen, Bd. lxviii. S. 101.

([489]) p. 290.—Faraday on Atmospheric Magnetism, in "Exper. Researches on Electricity," 25th and 26th Series (Phil. Trans. for 1851, Part 1), § 2774, 2780, 2881, 2892—2968; and for the historical part of the research, § 2847.

([490]) p. 291.—Compare Nervander, of Helsingfors, in the Bulletin de la Classe physico-mathém. de l'Acad. de St.-Pétersbourg, T. iii. 1845, p. 30—32; and Buys-Ballot, of Utrecht, in Poggend. Annalen der Physik, Bd. lxviii. 1846, S. 205—213.

([491]) p. 291.—I have distinguished by marks of quotation what I have taken in p. 291 to p. 294 from Schwabe's manuscript communications. The observations of the years 1826 to 1843 were previously published in Schumacher's Astron. Nachr. No. 495, Bd. xxi. 1844, S. 235.

([492]) p. 295.—Sir John Herschel, Cape Obs. p. 434.

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([493]) p. 297.—Kosmos, Bd. i. S. 207 and 442, Anm. 49; Eng. ed. p. 188.

([494]) p. 298.—Gesenius, in the Hallischen Litteratur-Zeitung, 1822, No. 101 and 102 (Ergänzungs bl. S. 801—812). The Chaldeans regarded the Sun and Moon as the two principal divinities, and the five planets only as presided over by Genii.

([495]) p. 298.—Plato, in the Timæus, p. 38, Steph.

([496]) p. 298.—Böckh de Platonico systemate cœlestium globorum et de vera indole astronomiæ Philolaicæ, p. xvii.; and the same author in the Philolaos, 1819, S. 99.

([497]) p. 298.—Jul. Firmicus Maternus, Astron. libri viii. (ed. Pruckner, Basil. 1551), lib. ii. cap. 4; of the time of Constantine.

([498]) p. 298.—Humboldt, Monumens des peuples indigènes de l'Amérique, T. ii. p. 42—49. At that early date, 1812, I called attention to the points of analogy between the zodiac of Bianchini and that of Dendera. Compare Letronne, Observations critiques sur les représentations zodiacales, p. 97; and Lepsius, Chronologie der Aegypter, 1849, S. 80.

(499) p. 298.—Letronne sur l'origine du Zodiaque grec, p. 29; Lepsius, Chronologie, S. 83. Letronne contested the ancient Chaldean origin of the "planetary week" on account of the number 7.

(500) p. 298.—Vitruv. de Archit. ix. 4 (ed. Rode, 1800, p. 209). Neither Vitruvius nor Martianus Capella give the Egyptians as the authors of a system according to which Mercury and Venus were regarded as the satellites of the Sun, that orb being itself viewed as a planet. Vitruvius says:—"Mercurii autem et Veneris stellæ circum Solis radios. Solem ipsum, uti centrum, itineribus coronantes, regressus retrorsum et retardationes faciunt."

(501) p. 298.—Martianus Mineus Felix Capella de nuptiis philos. et Mercurii, lib. viii. ed. Grotii, 1599, p. 289: "Nam Venus Mercuriusque licet ortus occasusque quotidianos ostendant, tamen eorum circuli Terras omnino non ambiunt, sed circa Solem laxiore ambitu circulantur. Denique circulorum suorum centron in Sole constituunt, ita ut supra ipsum aliquando"....... As this passage is entitled "Quod Tellus non sit centrum omnibus planetis," it might indeed, as Gassendi asserts, have exercised some influence on the first views of Copernicus,—more so than the passages attributed to the great geometer, Apollonius of Perga. Copernicus, however, only says, "minime contemnendum arbitror, quod Martianus Capella scripsit, existimans quod Venus et Mercurius circumerrant Solem in medio existentem." Compare Kosmos, Bd. ii. S. 350 and 503, Anm. 34; Engl. ed. p. 309 and cix., Note 474.

(502) p. 299.—Henri Martin, in his commentary on the Timæus (Etudes sur le Timée de Platon, T. ii. p. 129—133), appears to me to have elucidated in a very happy manner the passage of Macrobius on the "ratio Chaldæorum," which had misled the excellent Ideler, in Wolff's and Buttmann's Museum der Alterthums-Wissenschaft, Bd. ii. S. 443, and in his Memoir on Eudoxus, p. 48. Macrobius (in Somn. Scipionis, lib. i. cap. 19, lib. ii. cap. 3, ed. 1694, pag. 64 and 90) does not appear to have known anything of the system of Vitruvius and Martianus Capella, in which Mercury and Venus are satellites of the Sun, which itself moves, together with the remaining planets, round the Earth, which is fixed in the centre. He merely enumerates the differences in the succession of the orbits of the Sun, Venus, Mercury, and the Moon, according to the assumptions of Cicero. He says, "Ciceroni, Archimedes et Chaldæorum ratio consentit, Plato Ægyptios secutus est." When Cicero, in the eloquent description of the whole planetary system (Somn. Scip. cap. 4), exclaims "hunc (Solem) ut comites consequuntur Veneris alter, alter Mercurii cursus," he only points to the nearness to each other of the orbits of the Sun and of those two inferior planets, after having

previously enumerated the three "cursus" of Saturn, Jupiter, and Mars, all revolving round the unmoving Earth. The orbit of a secondary planet or satellite cannot include the orbit of a primary planet, and yet Macrobius says decidedly—"Ægyptiorum ratio talis est: circulus, per quem Sol discurrit, a Mercurii circulo ut inferior ambitur, illum quoque superior circulus Veneris includit." All are permanently parallel orbits, one including another.

([503]) p. 299.—Lepsius, Chronologie der Aegypter, Th. i. S. 207.

([504]) p. 299.—The mutilated name of the planet Mars, in Vettius Valens and Cedrenus, may probably answer to the name of Her-tosch, as Seb to Saturn. (See last-quoted work, p. 90 and 93.)

([505]) p. 300.—We find the most striking differences on comparing Aristot. Metaph. xii. cap. 8, pag. 1073, Bekker, with Pseudo-Aristot. de Mundo, cap. 2, pag. 392. In the last-mentioned work there already appear as the names of planets, Phæton, Pyrois, Hercules, Stilbon, and Juno; pointing to the time of Apuleius and the Antonines, when Chaldean astrology had already spread over the whole Roman empire, and denominations belonging to various nations were intermingled with each other. (Compare Kosmos, Bd. ii. S. 15 and 106, Anm. 18; Eng. ed. p. 14 and 111, Note 18.) Diodorus Siculus says expressly that the Chaldeans had first named the planets after their Babylonian deities, and that it was thus this class of names had passed to the Greeks. Ideler (Eudoxus, S. 48), on the contrary, attributes these appellations to the Egyptians, and grounds his opinion on the ancient existence on the banks of the Nile of a seven days' planetary week (Handbuch der Chronologie, Bd. i. S. 180); but this hypothesis has been effectually refuted by Lepsius (Chronol. der Aeg. Th. i. S. 131). I will here bring together the synonymous names borne by the five ancient planets, taken from Erastothenes, from the author of the Epinomis (Philippus Opuntius?), from Geminus, Pliny, Theon of Smyrna, Cleomedes, Achilles Tatius, Julius Firmicus, and Simplicius: their preservation has probably been principally caused by attachment to the dreams of astrology.

Saturn: *φαινων*, Nemesis; also called by five authors "a sun" (Theon Smyrn. p. 87 and 165, Martin).

Jupiter: *φαέθων*, Osiris.

Mars: *πυρόεις*, Hercules.

Venus: *ἑωσφόρος*, *φωσφόρος*, Lucifer; *ἑσπερος*, Vesper; Juno; Isis.

Mercury: *στιλβων*; Apollo.

Achilles Tatius (Isag. in Phæn. Arati, cap. 17) thinks it strange that

Egyptians as well as Greeks should give the name of "the bright" to the faintest of all the planets (probably, he surmises, only because it brings good fortune). According to Diodorus, it was "because Saturn was the planet which made known the future with the most fulness and clearness." (Letronne, sur l'origine du Zodiaque grec, p. 33; and in the Journal des Savants, 1836, p. 17. Compare also Carteron, Analyse de Recherches Zodiacales, p. 97.) Names which pass from one nation to another by means of equivalents, do indeed often depend in their origin on accidental circumstances which it is impossible to trace; but yet it may be well to remark here, that, linguistically, φαινειν expresses merely shining; therefore, a faint, continuous, equable light: while στιλβειν supposes an interrupted more vividly bright and more *sparkling* light. The descriptive appellations—φαινων for the remoter planet, Saturn; and στιλβων for the nearer planet, Mercury—appear to me the more appropriate, because, as I have already remarked (Kosmos, Bd. iii. S. 84; Eng. ed. p. 66), in the daytime, in Fraunhofer's large Refractor, Saturn and Jupiter appear faint in their light, in comparison with the sparkling Mercury. There is indicated, as Professor Franz remarks, a successive increase of brightness from Saturn (φαινων) to Jupiter, the lustrous guider of the luminous chariot (φαέθων); to the coloured glowing Mars (πυρόεις); to Venus (φωσφόρος); and to Mercury (στιλβων).

The Indian appellation of the "slow-moving" (sanaistschara), for Saturn, being known to me, it led me to inquire from my celebrated friend Bopp, whether, in the Indian names for the planets, as in those of the Greeks, and possibly of the Chaldeans, it was possible to distinguish between mythological and descriptive names. I subjoin the information for which I am indebted to this great philologist; placing the planets, however, as in the above table, in the order of succession of their real distances from the Sun (beginning with the greatest distance), instead of in the order in which they are arranged in the Amarakoscha (in Colebrooke, p. 17 and 18). According to the Sanscrit nomenclature, there appear in fact, among five names, to be three which are descriptive ones: those for Saturn, Mars, and Venus.

"*Saturn:* sanaitschara, from 'sanais, slow, and tschara, moving; also sauri, a name of Vishnu (derived as a patronymic from 'sûra, grandfather of Krishna), and 'sani. The planetary name 'sani-vara, for dies Saturni, is radically allied with the adverb 'sanais, slow. The appellations of the days of the week according to the planets do not, however, appear to have been known to Amarasinha. They are probably of later introduction.

"*Jupiter:* Vrihaspati; or, according to the more ancient Vedic mode of writing, which is followed by Lassen, Brihaspati: Lord of growth; a Vedic deity: from vrih (brih), to grow, and pati, lord.

"*Mars:* Angaraka (from angara, burning coal); also, lohitânga, the red body: from lôhita, red, and anga, body.

"*Venus:* a male planet, called 'sukra, *i. e.* the bright. Another appellation of this planet is daitya-guru: teacher, (guru) of the Titans, Daityas.

"*Mercury:* Budha (a planetary name not to be confounded with Buddha, the founder of a creed); also Rauhinêya, the son of the nymph Rohini, the consort of the Moon (soma); whence the planet is sometimes called saumya, a patronymic of the Sanscrit word for moon. The etymological root of both Budha and Buddha is budh, to know. It appears to me very improbable that Wuotan (Wotan, Odin) is connected with Budha. The conjecture has no doubt been principally founded on the external similarity of form, and on the agreement in the name of the day of the week, dies Mercurii, with the old Saxon Wôdanes-dag, and the Indian Budha-vara, Budha's day. Vâra signifies originally time, *e. g.* in bahuvârân, many times, or often; later it appears at the end of a composite form in the signification of day. Jacob Grimm (Deutsche Mythologie, S. 120) derives the Germanic Wuotan from the verb watan, vuot (our German waten; English, to wade), which signifies meare, transmeare, cum impetu ferri, and corresponds literally to the Latin vadere. Wuotan, Odinn, is, according to Jacob Grimm, the all-powerful, all-pervading Being: qui omnia permeat, as Lucan says of Jupiter."

Compare on the Indian name of the day of the week, on Budha and Buddha, and the days of the week generally, my brother's remarks in his work, Ueber die Verbindungen zwischen Java und Indien (Kawi Sprache, Bd. i. S. 187—190).

(506) p. 300.—Compare Letronne sur l'Amulette de Jules César et les Signes planétaires, in the Revue Archéologique, Année iii. 1846, p. 261. Salmasius saw in the most ancient planetary sign for the planet Jupiter, the initial letter of Ζεύς; and in that for Mars, an abbreviation of the name θούριος, The solar disc, employed as a sign, was rendered almost unrecognisable by a triangular obliquely issuing bundle of rays. As the Earth (apart from the Philolaic Pythagorean system) was not reckoned among the planets, Letronne considers the planetary sign employed for the Earth to have come into use subsequent to Copernicus. The remarkable passage of Olympiodorus, on the consecration of metals to particular planets, is borrowed

from Proclus, and was discovered by Böckh. (In the Basle edition it is in p. 14, and in Schneider's in p. 30.) Compare for Olympiodorus: Aristot. Meteor. ed. Ideler, T. ii. p. 163. The Scholion to Pindar (Isthm.), in which the metals are compared to the planets, also belongs to the Neo-Platonic School. (Lobeck, Aglaophamus in Orph. T. ii. p. 936.) By the same connection of ideas planetary signs came gradually to be employed as signs for the metals, and in particular cases even furnished names to metals, as mercury for quicksilver, argentum vivum, and hydrargyrus of Pliny. In the valuable collection of Greek manuscripts in the Paris Library, there are two manuscripts on the cabalistic, so-called sacred, art; one of which (No. 2250) mentions the metals consecrated to the planets without planetary signs, but the other (No. 2329), which is a kind of Chemical Dictionary, and belongs to the 15th century, combines the names of the metals with a small number of planetary signs. (Hofer, Histoire de la Chimie, T. i. p. 250.) In the Paris manuscript No. 2250, quicksilver is attributed to Mercury, and silver to the Moon; while in No. 2329, on the contrary, quicksilver is given to the Moon, and tin to Jupiter. Olympiodorus assigned the latter metal to Mercury:—so fluctuating were the mystical relations of the heavenly bodies to the "powers of the metals."

This is the place for alluding to the allotment to different planets of the several hours of the day, and of the several days of the short period of seven days, or the week, respecting the antiquity and the prevalence of which among remote nations, more correct views have very recently been put forward for the first time. The Egyptians, as is shown by Lepsius (Chronologie der Aegypter, S. 132), and testified by monuments reaching back to the very early times of the construction of the great pyramids, had originally short periods, similar to weeks, consisting not of seven, but of ten days. Three such decades formed one of the twelve months of the solar year. When we read in Dio Cassius (lib. xxxvii. cap. xviii.) "that the custom of calling the days of the week after the seven planets came first from the Egyptians, and had spread not very long ago from them to all other nations, and in particular to the Romans, among whom it had *already* become completely naturalised," we must not forget that this writer lived so late as the reign of Alexander Severus, and that since the first invasion of Oriental astrology under the Cæsars, and particularly in consequence of the great assemblage and intercourse of persons of so many nations and races at Alexandria, it had become usual among the people of the West to give the name of Egyptian to whatever seemed to be ancient. Without doubt the week of seven days was

most original and most general among the Semitic nations; not only among the Hebrews, but also among the Arabian Nomades long before Mahomet. I proposed to a learned investigator of Semitic antiquity, the Oriental traveller, Prof. Tischendorf, at Leipsic, the questions,—whether there were in the writings of the Old Testament, besides the Sabbath, any traces of names for the several days of the week (other than the second and third day of the schebua); and whether there could nowhere be found in the New Testament, at a time when foreign residents in Palestine certainly already pursued planetary astrology, any planetary denomination for a day of the week? The answer was: "Neither in the Old nor the New Testament are there any traces of appellations for any of the days of the week taken from the planets, and, moreover, none such can be found either in the Mischna or the Talmud. The custom was not to say 'the second or the third of the schebua,' but to count by the days of the month: the day before the Sabbath was called 'the 6th day,' without any addition. The word Sabbath was also applied directly to the week itself (Ideler, Handbuch der Chronologie, Bd. i. S. 480), whence we find in the Talmud, for the several days of the week: first, second, third of the Sabbath. The word ἑβδομὰς, for schebua, is not in the New Testament. The Talmud, of which the redaction extends from the second into the fifth century, has *descriptive* Hebrew names for particular planets, *i. e.* the *bright* Venus and the *ruddy* Mars. The name of Sabbatai (properly, Sabbath-star), given to Saturn, is particularly remarkable, as is also the circumstance that among the Pharisaic names of stars enumerated by Epiphanius, the name Hochab, Sabbath, is used for the planet Saturn. May this have had any influence in causing the day of the Sabbath to become the day of Saturn; Saturday, the Saturni sacra dies of Tibullus (Eleg. i. 3, 18)? A passage of Tacitus (Hist. v. 4) suggests additional considerations, taking the name of Saturn as applicable both to the planet and to a partly legendary, partly historical personage." (Compare also Fürst, Kultur- und Litteratur-geschichte der Juden in Asien, 1849, S. 40.)

The phases of the Moon in her different quarters must assuredly have earlier attracted the attention of hunting and pastoral nations than astrological fancies. We may, therefore, well assume with Ideler, that the week has arisen from the length of the synodical month, of which the fourth part contains on the average 7 days and ⅜ths; and that, on the other hand, references to the planetary series or the intervals between the planets, as well as to planetary hours and days, belong to a wholly different period, and to a more advanced, theory-loving civilisation.

Three different opinions have been propounded respecting the appellations of the different days of the week taken from the planets, and respecting the arrangement and sequence of the heavenly bodies,

Saturn,
Jupiter,
Mars,
Sun,
Venus,
Mercury, and
Moon,

as placed according to the oldest and most widely prevalent belief (Geminus, Elem. Astr. p. 4; Cicero, Somn. Scip. cap. 4; Firmicus, ii. 4), between the sphere of the fixed stars and the Earth,—itself immoveably at rest in the centre. Of the three views alluded to, one is taken from musical intervals; another from the astrological names of the planetary hours; and a third from the distribution of every three decans, or three planets who are the lords (domini) of these decans, among the twelve signs of the zodiac. We find the two first-named hypotheses in the remarkable passage in Dio Cassius, in which he wishes to explain (lib. xxxvii. cap. 17) why the day of Saturn, our Saturday, is kept by the Jews, according to their law, as the Sabbath. He says: "If we apply the musical interval, called διὰ τεσσάρων, the fourth, to the seven planets, according to their times of revolution, and assign to Saturn, which is the outermost of all, the first place, we come next to the fourth (the Sun), and then to the seventh (the Moon); and thus we obtain the planets in the order in which they follow each other in the names of the days of the week." The commentary to this passage is given by Vincent, "sur les Manuscrits grecs relatifs à la Musique," 1847, p. 138: compare also Lobeck, Aglaophamus, in Orph. p. 941—946. The second explanation of Dio Cassius is taken from the periodical series of the planetary hours. He says: "If we begin to count the hours of the day and night from the first hour of the day, calling the first hour that of Saturn, the second that of Jupiter, the third hour belonging to Mars, the fourth to the Sun, the fifth to Venus, the sixth to Mercury, and the seventh to the Moon, according to the order assigned by the Egyptians to the planets; and if we always begin again, and go through the same round,—we shall find that, after passing through the twenty-four hours, the first hour of the next day is that of the Sun, the first hour of the third day that of the Moon, the first of the fourth that of Mars,—and, in short, that the first hour of each day will be that of the planet from which the day is called." Thus Paulus Alexandrinus, an astronomer and

mathematician of the fourth century, calls regent or ruler of each day of the week the planet whose name falls to the first hour of that day.

This mode of explanation of the names of the days of the week has been hitherto very generally received as the correct one; but Letronne grounds upon the long neglected zodiacal circle of Bianchini (which is preserved in the Louvre, and to which I myself, in the year 1812, recalled the attention of antiquarians, on account of the remarkable combination of a Greek with a Kirgiso-Tartar zodiac) the belief that a third mode of explanation corresponds best to the distribution of every three planets to a sign of the zodiac. (Letronne, "Observ. crit. et archéol. sur l'objet des représentations zodiacales," 1824, p. 97—99.) This distribution of the planets among the thirty-six decans of Dodecatomery is quite that which is described by Julius Firmicus Maternus (ii. 4) as "signorum decani eorumque domini." If we distinguish in each sign the planet which is the first of the three, we obtain the succession of the planetary days in the week. (In Virgo—*Sun*, Venus, Mercury; in Libra—*Moon*, Saturn, Jupiter; in Scorpio—*Mars*, Sun, Venus; in Sagittarius—*Mercury* ...... may here serve as instances of the first four days of the week:—Dies *Solis*, *Lunæ*, *Martis*, *Mercurii*.) As, according to Diodorus, the Chaldeans originally counted only five planets (the starry ones), not seven, so all those combinations in which periodical series are formed of more than five planets, appear to have not an ancient Chaldean, but rather a very late astrological origin. (Letronne, sur l'origine du zodiaque grec, 1840, p. 29.)

Some of my readers may perhaps be pleased to find here a farther very short explanation of the agreement between the order of succession of the planets as days of the week, and their order of succession and distribution among the decans in the zodiac of Bianchini. If, taking the so-called seven planets in the order of succession in which they were arranged according to the custom of the ancients, and assigning to each a letter—(Saturn $a$, Jupiter $b$, Mars $c$, Sun $d$, Venus $e$, Mercury $f$, Moon $g$)—we make of these seven members the periodical series

$$a\ b\ c\ d\ e\ f\ g,\quad a\ b\ c\ d\ldots\ldots\ldots;$$

then we obtain,—1st, by missing two members in the distribution among the decans, each one of which contains three planets (of which the *first* in each zodiacal sign gives its name to the day of the week), the new periodical series, $a\ d\ g\ c\ f\ b\ e,\quad a\ d\ g\ c\ldots\ldots\ldots$

*i. e.* Dies Saturni, Solis, Lunæ, Martis, &c.; and 2ndly, the same new series $a\ d\ g\ c\ldots\ldots\ldots$

by the method given by Dio Cassius of the twenty-four planetary hours, according

to which the successive days of the week take their names from the planet which rules over the first hour of the day; so that we have alternately to take a member of the periodical planetary series of seven members, and to pass over or omit 23 members. Now, in a periodical series, it is indifferent whether we omit a certain number of members, or this number augmented by any multiple of the number of members in the period (which in this case is 7). By omitting 23 $(= 3 \times 7 + 2)$ members in the second method, that of the planetary hours, we are conducted therefore to the same result as by the first method of the decans, in which only two members were passed over.

I have already referred in the preceding note ([505]), to the remarkable resemblance between the fourth day of the week, dies Mercurii, the Indian Budha-vâra, and the old Saxon Wodânes-dag. (Jacob Grimm, Deutsche Mythologie, 1844, Bd. i. S. 114.) The identity asserted by Sir Wm. Jones between Buddha and Odin, Woden, Wuotan or Wotan, so celebrated in northern heroic Sagas, and in the history of northern civilisation, may perhaps be rendered still more interesting by remembering the name of Wotan as that of a half-mythical, half-historical personage in the central parts of the New Continent, respecting whom I collected many notices in my work on the Monuments and Myths of the Aborigines of America (Vues des Cordillères et Monumens des Peuples indigènes de l'Amérique, T. i. p. 208 and 382—384; T. ii. p. 356). According to the traditions of the natives of Chiapa and Soconusco, this American Wotan was the grandson of the man who in the great inundation saved himself in a boat and renewed the race of mankind. He caused great buildings to be constructed, during the erection of which (as during that of the Mexican pyramid of Cholula), confusion of tongues, strife, and dispersion of tribes ensued. His name passed (like the name of Odin in the Germanic North) into the Calendar-system of the natives of Chiapa. One of the five-day periods, four of which formed the month of the Chiapaneks, as well as of the Aztecs, was called after him. While, among the Aztecs, the names and the signs of the different days were taken from animals and plants, the natives of Chiapa (properly, Teochiapan) designated the days of the month by the names of twenty leaders, who, *coming from the North*, had conducted them thus far towards the South. The four most heroic of these leaders—Wotan or Wodan, Lambat, Been, and Chinar—gave their names to the opening days of the small periods, or weeks of five days,—a post which among the Aztecs was occupied by the symbols of the four elements. Wotan and the other leaders belonged incontestably to the race of the Toltecs, whose invasion took place in the seventh century. Ixtlilxochitl (his Christian name was Fernando de Alva),

the first historian of his nation (the Aztecs), says decidedly, in the manuscripts prepared by him so early as the beginning of the 16th century, that the province of Teochiapan, and the whole of Guatimala, from one coast to the other, was peopled by Toltecs; and even that at the commencement of the Spanish Conquest there still lived in the village of Teopixca a family who boasted of their descent from Wotan. The Bishop of Chiapa, Francisco Nuñez de la Vega, who was President of a Provincial-Concilium in Guatimala, collected many things respecting the legends of the American Wotan in his "Preambulo de las Constituciones diocesanas." Whether the tradition of the first Scandinavian Odin (Odinn, Othinus) or Wuotan, said to have come from the banks of the Don, has any historic foundation, is still very uncertain (Jacob Grimm, Deutsche Mythologie, Bd. i. S. 120—150). The identity of the American and Scandinavian Wotan, which does not indeed rest solely on the mere similarity of sound, still remains as doubtful as does the identity of Wuotan (Odinn) and Buddha, or that of the names of the Indian founder of the Buddhistic religion and the planet Budha.

The supposed existence of a Peruvian week of seven days, so often adduced as a Semitic similarity between the two continents in respect to the manner of dividing time, rests, as Pater Acosta, who visited Peru soon after the Spanish Conquest, had already shown (Hist. natural y moral de las Indias, 1591, lib. vi. cap. 3), on a mere error; and the Inca Garcilaso de la Vega himself corrected his earlier statement (Parte i. lib. ii. cap. 35), by saying distinctly, that in each of the months, which were reckoned by the Moon, there were three festival days, and that the people were to work eight days and rest the ninth day (Parte i. lib. vi. cap. 23). The so-called Peruvian weeks were therefore of nine days. (See my "Vues des Cordillères," T. i. p. 341—343.)

([507]) p. 301.—Böckh über Philolaos, S. 102 and 117.

([508]) p. 304.—We ought to distinguish, in the history of discoveries, beween the epoch when a discovery was made, and that of its first publication. By not attending to this distinction, discordant and erroneous dates have been introduced into astronomical compendiums. Thus, for example, Huygens discovered the sixth satellite of Saturn, Titan, on the 25th of March, 1655, (Hugenii Opera varia, 1724, p. 523), and published the discovery for the first time on the 5th of March, 1656. (Systema Saturnium, 1659, p. 2.) Huygens, who had been uninterruptedly occupied with Saturn since the month of March 1655, enjoyed the full and undoubted view of the open ring on the 17th of December, 1657 (Syst. Sat. p. 21), but did not publish

his scientific explanation of all the phænomena until 1659. (Galileo had only thought that he saw on either side of the planet two detached, circular disks.)

([509]) p. 305.—Kosmos, Bd. i. S. 95; Engl. ed. p. 82. Compare also Encke in Schumacher's Astr. Nachr. Bd. xxvi. 1848, No. 622, S. 347.

([510]) p. 315.—Böckh de Platonico syst. p. xxiv., and in his Philolaos, S. 100. The order of arrangement of the planets, which, as we have just seen (Note [510]), gave occasion to the planetary appellations of the days of the week, and which was that of Geminus, is distinctly called by Ptolemy (Almag. xi. cap. 1) the most ancient. He blames the motives which had led "more recent" writers to "place Venus and Mercury beyond the Sun."

([511]) p. 315.—The Pythagoreans defended the belief in the reality of the production of musical sounds by the revolution of the spheres, by asserting that we hear only when there is alternation of sound and of silence. (Aristot. de Cœlo, ii. 9, pag. 290, No. 24—30, Bekker.) The music of the spheres is also said to remain unheard by reason of a deafening effect. (Cicero de rep. vi. 18.) Aristotle himself terms the Pythagorean myth on this subject, pleasing and ingenious, κομψῶς και περιττῶς), but *untrue* (l. c. No. 12—15).

([512]) p. 315.—Böckh, in the Philolaos, S. 90.

([513]) p. 316.—Plato de republica, x. p. 617. He estimates the distances of the planets according to two entirely different progressions—one duplicate, the other triplicate—whence there arises the series 1, 2, 3, 4, 9, 8, 27. It is the same series which is found in the Timæus (p. 35, Steph.), in speculations relative to the arithmetical division of the soul of the Universe which the Demiurgus undertakes. Plato has considered the two geometrical progressions 1 . . 2 . . 4 . . 8 and 1 . . 3 . . 9 . . 27 conjointly, taking each successive number alternately from either series; whence, as above, 1 . . 2 . . 3 . . 4 . . 9. Compare Böckh in the "Studien von Daub und Creuzer," Bd. iii. S. 34—43; Martin, E'tudes sur le Timée, T. i. p. 384, and T. ii. p. 64. Compare also Prevost "sur l'âme d'après Platon," in the Mém. de l'Acad. de Berlin pour 1802, p. 90 and 97; and the same writer in the Bibliothèque britannique, Sciences et Arts, T. xxxvii. 1808, p. 153.

([514]) p. 316.—See the ingenious treatise of Professor Ferdinand Piper, entitled "Von der Harmonie der Sphären," 1850, S. 12—18. The younger Ideler has treated in detail, and with much learned criticism, the subject of the supposed relation of the seven vowels of the ancient Egyptian language to the seven planets; and Gustav Seyffarth's ideas (refuted even by the researches of Zoega and Tölke) respecting supposed astrological vowel-filled hymns of the Egyptian priests, discussing them in connection with passages

of the Pseudo-Demetrius Phalereus (perhaps Demetrius of Alexandria), an epigram of Eusebius, and a gnostic manuscript at Leyden. See Hermapion, 1841, Pars i. p. 196—214, and compare with it Lobeck, Aglaoph. T. ii. p. 932.

([515]) p. 316.—On the gradual development of Kepler's musical ideas, see Apelt's Commentary on the Harmonice Mundi, in his work entitled Johann Keppler's Weltansicht, 1849, S. 76—116. (Compare also Delambre, Hist. de l'Astr. mod. T. i. p. 352—360.)

([516]) p. 316.—Kosmos, Bd. ii. S. 353; Engl. ed p. 313.

([517]) p. 317.—Tycho Brahe had annihilated the crystal spheres to which the planets were supposed to be attached. Kepler praises this enterprise, but yet persists in representing the sphere of the fixed stars as a solid globular shell of two German miles in thickness, on which shine twelve stars of the first magnitude, all at an equal distance from the Earth, and having a particular relation to the angles of an icosaëdron. The fixed stars "lumina sua ab *intus* emittunt:" the planets were also supposed to be self-luminous until he "learnt better from Galileo!" Although, like several of the ancients, and like Giordano Bruno, he regarded all the fixed stars as suns similar to our own, yet he was less favourable than I have stated in an earlier volume (Kosmos, Bd. ii. S. 365; Engl. ed. p. 324) to the opinion "which he had pondered," that they are all surrounded by planets. Compare Apelt's work, quoted above, S. 21—24.

([518]) p. 317.—Delambre, in the Hist. de l'Astr. mod. T. i. p. 314, in his astronomically but not astrologically complete extracts from Kepler's Sämmtlichen Werken, p. 314—615, first called attention to the planet conjectured by Kepler to exist between Mercury and Venus. "On n'a fait aucune attention à cette supposition de Kepler, quand on a formé des projets de découvrir la planète qui (selon une autre de ses prédictions) devait circuler entre Mars et Jupiter."

([519]) p. 317.—The remarkable passage respecting the filling up of a gap or hiatus between Mars and Jupiter, is found in Kepler's Prodromus Dissertationum cosmographicarum, continens Mysterium cosmographicum de admirabili proportione orbium cœlestium, 1596, p. 7:—"Cum igitur hac non succederet, alia via, mirum quam audaci, tentavi aditum. Inter Jovem et Martem interposui novum planetam, itemque alium inter Venerem et Mercurium, quos duos forte ob exilitatem non videamus, iisque sua tempora periodica ascripsi. Sic enim existimabam me aliquam æqualitatem proportionum effecturum, quæ proportiones inter binos versus Solem ordine minuerentur, versus fixas augescerent: ut propior est Terra Veneri quantitate

orbis terrestris, quam Mars Terræ in quantitate orbis Martis. Verum hoc pacto neque unius planetæ interpositio sufficiebat ingenti hiatu. Jovem inter et Martem: manebat enim major Jovis ad illum novum proportio, quam est Saturni ad Jovem. Rursus alio modo exploravi......." Kepler was twenty-five years old when he wrote this. We see how his mobile spirit set up hypotheses, and quickly abandoned and exchanged them for others. Through all such changes he preserved a hopeful confidence of discovering *numerical laws*, even where, amongst the most varied perturbations of attracting forces (perturbations of which our ignorance of the accompanying conditions forbids all attempt at calculating the combined action), the matter of which the planetary orbs were formed has been consolidated into bodies revolving in some instances singly in simple orbits, almost parallel to each other; in others in groups, and in wonderfully intersecting and intertwining orbits.

([520]) p. 318.—Newtoni, Opuscula mathematica, philosophica et philologica, 1744, T. ii. Opusc. xviii. p. 246: "Chordam musice divisam potius adhibui, non tantum quod cum phænomenis (lucis) optime convenit, sed quod fortasse, aliquid circa colorum harmonias (quarum pictores non penitus ignari sunt), sonorum concordantiis fortasse analogas, involvat. Quemadmodum verisimilius videbitur animadvertenti affinitatem, quæ est inter extimam Purpuram (Violarum colorem) ac Rubedinem, colorum extremitates, qualis inter octavæ terminos (qui pro unisonis quodammodo haberi possunt) reperitur......." Compare also Prevost, in the Mém. de l'Acad. de Berlin pour 1802, p. 77 and 93.

([521]) p. 318.—Seneca, Nat. Quæst. vii. 13: "Non has tantum stellas quinque discurrere, sed solas observatas esse: ceterum innumerabiles ferri per occultum."

([522]) p. 319.—As I could not feel satisfied with the explanations which Heyne had given (De Arcadibus luna antiquioribus, in Opusc. acad. Vol. ii. p. 332), of the origin of the widely prevalent astronomical myth of the Proselenes, I was much rejoiced at receiving a new and very happy solution of the problem from my ingenious philological friend, Professor Johannes Franz. This solution is not connected either with the construction of the calendar by the Arcadians, or with their worship of the Moon. I confine myself to an extract from an inedited and more comprehensive discussion. "In a work in which I have imposed on myself the obligation of frequently connecting our completer knowledge with the knowledge of the ancients, and even with

tradition, more or less prevalent opinions or beliefs, I think that the following explanation may not be unwelcome to a portion of my readers :—

"We begin with some leading passages from the ancients, which treat of the Proselencs. Stephanus, of Byzantium (V. Ἀρκάς) mentions the logograph Hippys, of Rhegium, a contemporary of Darius and Xerxes, as the first who called the Arcadians *προσελήνους*. The Scholiasts ad Apollon. Rhod. iv. 264, and ad Aristoph. Nub. 397, concur in saying, that the high antiquity of the Arcadians is most clearly shown by their being called *προσέληνοι*; and that they would seem to have been there before the Moon, as is also said by Eudoxus and Theodorus; to which the latter adds that the Moon appeared a short time before the combat of Hercules. Aristotle, in speaking of the civil constitution of the Tegeates, says that the barbarians who previously inhabited Arcadia were driven out by the later Arcadians before the Moon appeared, and were called on that account *ροσέληνοι*. Others say that Endymion discovered the revolutions of the Moon, and that as he was an Arcadian, his countrymen were called after him *προσέληνοι*. Lucian speaks in terms of censure, saying (Astrolog. 26) that the Arcadians, from want of understanding, and from folly, asserted that they were a people more ancient than the Moon. In Schol. ad Æschyl. Prom. 436, it is remarked: *προσελούμενον* is *ὑβρίζόμενον*, whence also the Arcadians are termed *προσέληνοι*, because they have too much pride. The passages in Ovid respecting the prelunar existence of the Arcadians are well known. Very recently the idea has been propounded that the ancients were themselves generally deceived by the form *προσεληνοι*; the word (properly, *προελληνοι*) signifying prehellenic, as Arcadia was a Pelasgic country."

"If, now, it can be proved," continues Professor Franz, "that another nation connects its descent with another heavenly body, we may be spared the trouble of having recourse to illusive etymologies; and the means of such proof do actually exist in the best form. The learned Rhetor Menander (about A.D. 270), says in his writing "de encomiis" (sect. ii. cap. 3, ed. Heeren) as follows :—A third topic of praise is afforded by time, as is the case with all that is most ancient; as when we say of a city or of a country, that it was built or was settled before this or that star or luminary,—or coeval with the stars,—or before or soon after the flood: as the Athenians assert that they were coeval with the Sun, the Arcadians that they were more ancient than the Moon, and the Delphians that they originated immediately after the flood: for these are eras or periods of commencement in time.

"Thus Delphi, whose connection with Deucalion's flood is also otherwise testified (Pausan. x. 6), is surpassed in antiquity by Arcadia, and Arcadia by Athens. Apollonius Rhodius, who imitates older examples, speaks quite in accordance herewith where he says (iv. 261) that Egypt was inhabited before all other countries; "when as yet not all the luminaries of heaven had begun their course; as yet the people of Danaus were not, neither Deucalion's race; only the Arcadians were in existence; of whom it is said that they lived before the Moon, feeding on acorns from the oaks of the mountains." So also Nonnus (xli.) says of the Syrian Beroe, that it was inhabited before the Sun.

Such a custom of taking supposed epochs in the construction of the Universe as chronological eras, belongs to a period in modes of contemplation, in which all imagery is, as yet, more vivid than at later epochs, and is nearly allied to genealogical local poetry. Thus it is even not improbable that the tale of the combat of the giants in Arcadia, sung by an Arcadian poet, and to which allusion is made in the words referred to above of the ancient Theodorus "(whom some regard as a Samothracian, and whose work must have been a very comprehensive one), may have given occasion to the diffusion of the epithet προσέληνοι applied to the Arcadians." Respecting the double name of "Arkades Pelasgoi," and the distinction drawn between a more ancient and more modern population of Arcadia, compare the excellent work called "der Peloponessos," by Ernst Curtius, 1851, S. 160 and 180. In the New Continent, also, as I have shown elsewhere (see my "Kleine Schriften," Bd. i. S. 115), the tribe of the Muyscas or Mozcas, on the high table-land of Bogota, boasted in its historical myths of a proselenic antiquity. They connected the origin of the Moon with the tradition of a great inundation, which a woman who accompanied the wonder-working personage Botschika, occasioned by her magic arts. Botschika drove away the woman (who was called Huythaca or Schia). She left the earth and became the Moon, "which till then had never given light to the Muyscas." Botschika, taking pity upon mankind, opened with a strong hand the steep rocky wall near Canoas, where the Rio de Funzha now precipitates itself, in the celebrated waterfall of the Tequendama. The valley, which had previously been filled with water, was thus laid dry,—a geognostical romance which is often repeated, as, for example, in the closed Alpine Valley of Cashmeer, where the powerful remover of the waters is called Kasyapa.

(523) p. 320.—"Karl Bonnet, Betrachtung über die Natur, ubersetzt von Titius," 2d edition, 1772, S. 7, Note 2, (the first edition was in 1766). In the

original work of Bonnet there is not even an allusion to such a law of distances. (Compare also Bode, Anleit. zur Kenntniss des gestirnten Himmels, 2te Aufl. 1772, S. 462.)

([524]) p. 321.—As Titius made the distance from the Sun to Saturn, then regarded as the outermost planet, = 100, the several distances according to the so-called progression,

$$4,\ 4+3,\ 4+6,\ 4+12,\ 4+24,\ 4+48, \text{ ought to be,—}$$

| Mercury. | Venus. | Earth. | Mars. | Small Planets. | Jupiter. |
|---|---|---|---|---|---|
| $\frac{4}{100}$ | $\frac{7}{100}$ | $\frac{10}{100}$ | $\frac{16}{100}$ | $\frac{28}{100}$ | $\frac{52}{100}$ |

whence, taking the distance of Saturn from the Sun at 197·3 millions of German geographical miles (789·2 Engl.), we have the following distances of the planets from the Sun, estimated according to the same scale :—

| Distances according to Titius in Geographical German Miles, 15 to a Degree. | | | Actual Distances in Miles, 15 to a Degree. | |
|---|---|---|---|---|
| Mercury | 7·9 | millions. | 8·0 | millions. |
| Venus | 13·8 | ,, | 15·0 | ,, |
| Earth | 19·7 | ,, | 20·7 | ,, |
| Mars | 31·5 | ,, | 31·5 | ,, |
| Small planets | 55·2 | ,, | 55·2 | ,, |
| Jupiter | 102·6 | ,, | 107·5 | ,, |
| Saturn | 197·3 | ,, | 197·3 | ,, |
| Uranus | 386·7 | ,, | 396·7 | ,, |
| Neptune | 765·5 | ,, | 621·2 | ,, |

([525]) p. 321.—Wurm, in Bode's Astron. Jahrbuch für das J. 1790, S. 168; and Bode, Von dem neuen zwischen Mars und Jupiter entdeckten achten Hauptplaneten des Sonnensystems, 1802, S. 45. With Wurm's numerical correction, the series of distances from the Sun is :—

| | Parts. | | | | | | |
|---|---|---|---|---|---|---|---|
| Mercury | 387 | | | | | | |
| Venus | 387 | + | | | 293 | = | 680 |
| Earth | 387 | + | 2 | × | 293 | = | 973 |
| Mars | 387 | + | 4 | × | 293 | = | 1559 |
| Small planets | 387 | + | 8 | × | 293 | = | 2731 |
| Jupiter | 387 | + | 16 | × | 293 | = | 5075 |
| Saturn | 387 | + | 32 | × | 293 | = | 9763 |
| Uranus | 387 | + | 64 | × | 293 | = | 19139 |
| Neptune | 387 | + | 128 | × | 293 | = | 37891 |

In order to supply the means of examining the accuracy of these results, I subjoin once more the actual mean distances of the planets as at present recognised, and in the same table the numbers which, two centuries and a half ago, Kepler regarded as the true values according to Tycho Brahe's observations. I take the latter from Newton's paper, entitled De Mundi Systemate (Opuscula math., philos. et philol. 1744, T. ii. p. 11).

| Planets. | True Distances. | Results of Kepler. |
|---|---|---|
| Mercury ...................... | 0·38709 | 0·38806 |
| Venus ......................... | 0·72333 | 0·72400 |
| Earth ......................... | 1·00000 | 1·00000 |
| Mars ........................... | 1·52369 | 1·52350 |
| Juno ........................... | 2·66870 | — |
| Jupiter ........................ | 5·20277 | 5·19650 |
| Saturn ........................ | 9·53885 | 9·51000 |
| Uranus ........................ | 19·18239 | — |
| Neptune ...................... | 30·03628 | — |

(526) p. 324.—The Sun, which Kepler, probably from enthusiasm for the "divina inventa" of his justly celebrated contemporary William Gilbert, regarded as magnetic, and whose rotation in the same direction as the planets he maintained before the solar spots had been discovered, is declared by Kepler to be "the densest of all celestial bodies, because he moves all the rest which belong to his system." (Comment. de motibus Stellæ Martis, cap. 23; and in Astronomiæ pars optica, cap. 6.)

(527) p. 324.—Newton de Mundi Systemate, in Opusculis, T. ii. p. 17: "Corpora Veneris et Mercurii majore Solis calore magis concocta et coagulata sunt. Planetæ ulteriores, defectu caloris, carent substantiis illis metallicis et mineris ponderosis quibus Terra referta est. Densiora corpora quæ Soli propiora: ea ratione constabit optime pondera Planetarum omnium esse inter se ut vires."

(528) p. 328.—Mädler, Astronomie, § 193.

(529) p. 329.—Humboldt de Distributione geographica Plantarum, p. 104 (Ansichten der Natur, Bd. i. S. 131 bis 133).

(530) p. 330.—L'étendue entière de cette variation serait d'environ 12 degrès, mais l'action du Soleil et de la Lune l'a reduit à peu près à trois degrès (centésimaux). Laplace, Expos. du Syst. du Monde, p. 303.

(531) p. 330.—I have shewn elsewhere by the comparison of numerous mean annual temperatures, that in Europe, from the North Cape to Palermo, a dif-

ference of one degree of geographical latitude corresponds very nearly to 0°·5 of the Centigrade thermometer (0°·9 Fahr.), but that in the system of temperatures on the American coast from Boston to Charlestown, the same difference of latitude corresponds to 0°·9 Centigrade (1°·62 Fahr.); Asie Centrale, T. iii. p. 229.

(532) p. 332.—Kosmos, Bd. ii. S. 402, Anm. 6 (Eng. ed. p. xxvii. Note 146).

(533) p. 332.—Laplace, Expos. du Système du Monde (5ème éd.) p. 303, 345, 403, 406, and 408; the same in the Connaissance des tems pour 1811, p. 386; Biot, Traité élèm. d'Astr. physique, T. i. p. 61, T. iv. p. 90—99, and 614—623.

(534) p. 333.—Garcilaso, Comment. Reales, Parte i. lib. ii. cap. 22—26; Prescott, Hist. of the Conquest of Peru, Vol. i. p. 126. The Mexicans had among their twenty hieroglyphic signs of days, one which they held in particular honour, called Ollin-tonatiuh, or "that of the four motions of the Sun," and which was prefixed to the great cycle renewed every 52 = 4 × 13 years, and had reference to the Sun's path (expressed hieroglyphically by footsteps), intersecting the solstices and equinoxes. In the finely painted Aztec manuscript, formerly preserved in the Villa of Cardinal Borgia at Veletri, and from which I have borrowed much important information, there is the remarkable astrological sign of a Cross, having written near it signs of days which would designate truly the passages of the Sun through the Zenith of the city of Mexico (Tenochtitlan), the Equator, and the Solstices, if the points (round disks), appended to the signs of days on account of the periodical series were equally complete in all the three passages spoken of. (Humboldt, Vues des Cordillères, Pl. xxxvii. No. 8, p. 164, 189, and 237). Nezahualpilli, King of Tezcuco, who was passionately devoted to the observation of the stars, had erected a building which Torquemada somewhat boldly terms an Astronomical Observatory, and of which the ruins were still seen by him. (Monarquia Indiana, lib. ii. cap. 64.) In the Raccolta di Mendoza, we see the representation of a priest observing the stars; as is expressed by a dotted line going from his eye to the observed star (Vues des Cordillères, Pl. lviii. No. 8, p. 289.)

(535) p. 335.—John Herschel, on the astronomical causes which may influence geological phenomena, in the Transact. of the Geological Society of London, 2d Ser. Vol. iii. P. i. p. 298: the same, in his Treatise of Astronomy, 1833 (Cab. Cyclop. Vol. xliii.) § 315.

(536) p. 336.—Arago, in the Annuaire pour 1834, p. 199.

(537) p. 336.—"Il s'ensuit (du théorème dû à Lambert) que la quantité de

chaleur envoyée par le Soleil à la Terre est la même en allant de l'équinoxe du printems à l'équinoxe d'automne qu'en revenant de celui-ci au premier. Le tems plus long que le Soleil emploie dans le premier trajet, est exactement compensé par son éloignement aussi plus grand; et les quantités de chaleur qu'il envoie à la Terre sont les mêmes pendant qu'il se trouve dans l'un ou l'autre hémisphère, boréal ou austral."—Poisson, sur la Stabilité du système planétaire, in the Connaiss. des tems pour 1836, p. 54.

(538) p. 337.—Arago, in the Annuaire above cited, p. 200—204. L'excentricité," says Poisson, in the Connaissance des Tems, above cited, pp. 38 and 52, "ayant toujours été et devant toujours demeurer très petite, l'influence des variations séculaires de la quantité de chaleur solaire reçue par la Terre sur la temperature moyenne parait aussi devoir être tres limitée.—On ne saurait admettre que l'éxcentricité de la Terre, qui est actuellement environ un soixantième, ait jamais été ou devienne jamais un quart, comme celle de Junon ou de Pallas."

(539) p. 338.—Outlines, § 432.

(540) p. 340.—The same, § 548.

(541) p. 341.—See in Mädler's Astronomie, S. 218, his attempt to determine the diameter of Vesta (66 ? German or 264 ? English geographical miles) with a magnifying power of 1000.

(542) p. 342.—In the statement formerly made, in the first volume of this work (p. 88–89), the equatorial semi-diameter of Saturn was taken as the basis.

(543) p. 342.—Compare Kosmos, Bd. iii. S. 281, Engl. ed. p. 195.

(544) p. 342.—In the Picture of Nature, in the first volume of Cosmos, I have treated in some detail of the Sun's movement of translation, S. 149-151; Eng. ed. p. 134—135. (Compare also Vol. iii. S. 266, Engl. ed. p. 181.)

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(545) p. 345.—Kosmos, Bd. iii. S. 389 and 411, Anm. 19 and 20; Engl. edit. p. 378 and 379, Notes 478 and 479.

(546) p. 345.—Compare the Observations of the Swedish mathematician, Bigerus Vassenius, at Gothenburg, during the total solar eclipse of the 2d of May, 1733, and Arago's comments on them in the Annuaire du Bureau des Longitudes pour 1846, p. 441 and 462. Dr. Galle, who observed on the 28th of July, 1851, at Frauenburg, saw the "freely suspended small cloud connected by three or even more threads with the hooked or curved gibbosity."

(547) p. 345.—Compare what was observed on the 8th of July, 1842, by a very practised observer, Captain Bérard, of the French navy, at Toulon.

"Il vit une bande rouge très mince, dentelée irrégulièrement." (Work above cited, p. 416.)

([548]) p. 346.—During the total solar eclipse of the 8th of July, 1842, this outline of the Moon had been distinctly perceived by four observers: such a circumstance had never been described as having taken place on previous similar occasions. The possibility of seeing the outer contour of the Moon appears to depend on the light given by the third outermost solar envelope and the corona. "La Lune se projette *en partie* sur l'atmosphère du Soleil. Dans la portion de la lunette où l'image de la Lune se forme, il n'y a que la lumière provenant de l'atmosphère terrestre. La Lune ne fournit rien de sensible et, semblable à un écran, elle arrête tout ce qui provient de plus loin et lui correspond. En dehors de cette image, et précisement à partir de son bord, le champ est éclairé *à la fois* par la lumière de l'atmosphère terrestre et par la *lumière de l'atmosphère solaire*. Supposons que ces deux lumières réunies forment un total plus fort de $\frac{1}{60}$ que la lumière atmosphérique terrestre, et, dès ce moment, le bord de la lune sera visible. Ce genre de vision peut prendre le nom de *vision negative;* c'est en effet par une *moindre intensité* de la portion du champ de la lunette où existe l'image de la Lune, que le *contour* de cette image est aperçu. Si l'image était *plus intense* que le reste du champ, la vision serait positive." Arago, in the work above cited, p. 384. (Compare also on this subject, Kosmos, Bd. iii. S. 70 and 114, Anm. 19; Engl. ed. p. 53, and Note 108.)

([549]) p. 346.—Kosmos, Bd. iii. S. 383—386, Eng. ed. p. 272—275.

([550]) p. 346.—Lepsius, Chronologie der Aegypter, Th. i. S. 92—96.

([551]) p. 346.—Kosmos, Bd. iii. S. 469, Anm. 13; Eng. ed. Note 505.

([552]) p. 346.—Kosmos, Bd. ii. S. 258, Engl. ed. p. 222.

([553]) p. 347.—Lalande, in the Mém. de l'Acad. des Sciences pour 1766, p. 498; Delambre, Hist. de l'Astr. ancienne, T. ii. p. 320.

([554]) p. 347.—Kosmos, Bd. iii. S. 468; Engl. ed. p. cvii.

([555]) p. 347.—On the occasion of the transit of Mercury of the 4th of May, 1832, Mädler and Wilhelm Beer (Beiträge zur phys. Kenntniss der himmlischen, Körper, 1841, S. 145), found the diameter of the planet 583 German, or 2332 English geographical miles; but in the edition of his Astronomie, published in 1849, Mädler preferred Bessel's result.

([556]) 348.—Laplace, Exposition du Syst. du Monde, 1824, p. 209. The celebrated author himself confessed, however, that he had based his determination of the mass of Mercury on the "hypothèse très précaire qui suppose les densités de Mercure et de la Terre réciproques à leur moyenne distance du

Soleil." I have not thought it necessary to notice either the supposed mountain ranges of 58,000 feet high which Schröter imagined himself to have measured on Mercury's disk, the existence of which was already doubted by Kaiser (Sternenhimmell, 1850, § 57); or Lemonnier's and Messier's statement (Delambre, Hist. de l'Astronomie au 18ème siècle, p. 222), of the visibility of an atmosphere of Mercury during the planet's transit across the Sun's disk; or the suppositions of trains of clouds passing over the planet, and transitory obscurations of its surface. During the transit of Mercury which I observed in Peru on the 8th of November, 1802, I paid great attention to the sharpness of the outline of the planet during the emersion, but I did not remark anything resembling an envelope.

(557) p. 348.—"The part of the orbit of Venus in which the planet may appear to us the brightest, so that it can be seen with the naked eye at noon, is situated intermediately between the inferior conjunction and the greatest digression, near to the latter, and nearly 40 degrees from the Sun, or from the place of the inferior conjunction. On a mean or average, Venus appears to us most bright and beautiful when distant 40° east or west of the Sun, when her apparent diameter, which at the inferior conjunction may increase to 66″, is only about 40″, and when the greatest breadth of the illuminated portion scarcely measures 10″. The nearness of the Earth then gives to the narrow bow a light so intense, that, in the absence of the Sun, it even casts shadows." (Littrow, Theorische Astronomie, 1834, Th. ii. S. 68.) Whether Copernicus predicted the necessity of a future discovery of the phases of Venus (as has been repeatedly stated, in Smith's Optics, Sect. 1050, and in several other books), has recently been shewn by Professor De Morgan's more exact examination of the work De Revolutionibus, as it has come down to us, to be extremely doubtful. (See the letter of Adams to the Rev. R. Main, dated 7th Sept. 1846, in Rep. of the Royal Astron. Soc. Vol. vii. No. 9, p. 142. Compare also Kosmos, Bd. ii. S. 362; Eng. ed. p. 321.)

(558) p. 350.—Delambre, Hist. de l'Astr. au 18ème siècle, p. 256—258. Bianchini's result has been defended by Hussey and Flaugergues: Hansen, whose authority stands justly so high, up to 1836 also regarded it as the more probable.

(559) p. 350.—Arago, on the remarkable Lilienthal observation of the 12th of August, 1790, in the Annuaire for 1842, p. 539. "Ce qui favorise aussi la probabilité de l'existence d'une atmosphère qui enveloppe Vénus, c'est le résultat optique obtenu par l'emploi d'une lunette prismatique. L'intensité de la lumière de l'intérieur du croissant est sensiblement plus faible que celle

des points situés dans la partie circulaire du disque de la planète." (Arago, Manuscripts of 1847).

([560]) p. 350.—Wilhelm Beer und Mädler, Beiträge zur physischen Kenntniss der himmlischen Körper, S. 148. The so-called satellite, or moon of Venus, which Fontana, Dominique Cassini, and Short, thought they had recognised, for which Lambert computed tables, and which was said to have been seen at Crefeld (Berliner Jahrbuch, 1778, S. 186), fully three hours after the emersion of Venus, in the middle of the Sun's disk, belongs to the astronomical myths of an uncritical period.

([561]) p. 350.—Philos. Transact. 1795, Vol. lxxxvi. p. 214.

([562]) p. 352.—Kosmos, Bd. iii. S. 103 and 133, Anm. 73; Engl. ed. p. 84, and Note 162.

([563]) p. 352.—"La lumière de la Lune est jaune, tandis que celle de Vénus est blanche. Pendant le jour la Lune parait blanche parcequ'à la lumière du disque lunaire se mêle la lumière bleue de cette partie de l'atmosphère que la lumière jaune de la Lune traverse." (Arago, in MSS. of 1847.) The most refrangible colours in the spectrum, those from blue to violet, unite in order to form white with their complementary colours, the less refrangible ones, from red to green. (Kosmos, Bd. iii. S. 309, Anm. 19; Engl. ed. p. lxxvii. Note 347.)

([564]) p. 353.—Forbes on the Refraction and Polarisation of Heat, in the Transactions of the Royal Soc. of Edinburgh, Vol. xiii. 1836, p. 131.

([565]) p. 354.—Lettre de Mr. Melloni à Mr. Arago sur la Puissance calorifique de la Lumière de la Lune, in the Comptes rendus, T. xxii. 1846, p. 541—544. Compare also, for the historical statements, the "Jahresbericht der physikalischen Gesellschaft zu Berlin," Bd. ii. S. 272. It has always appeared to me rather remarkable that, from the earliest times, when warmth was only determined by the feelings, the Moon first gave rise to the idea that light and warmth might be found separated. Among the Indians, the Moon, regarded as the King of the Stars, is surnamed in Sanscrit the "cold" ('sitala, hima) and also the cold-darting or cold-radiating (himân'su); while the Sun, with its many rays depicted as hands, is termed the "Creator of Heat" (nidâghakara). The spots on the Moon, in which western nations thought they could make out a face, represent, in the view of the Indians, a roebuck or a hare: hence the Sanscrit names of the Moon "Roe-bearer" (mrigadhara) or "Hare-bearer" (sa'sabhrit). (Schutz, "Five Cantos of the Bhatti-Kâvya, 1837, S. 19—23.) The Greeks complained "that the light of the Sun, reflected by the Moon, loses all heat, so that only feeble remains thereof com

to us." (Plutarch, in the Conversation "de facie quæ in orbe Lunæ apparet," Moralia ed. Wyttenbach, T. iv. Oxon. 1797, p. 793.) In Macrobius (Comm. in Somnium Scip. i. 19, ed Lud. Janus, 1848, p. 105) it is said: "Luna speculi instar lumen quo illustratur......rursus emittit nullum tamen ad nos perferentem sensum caloris: quia lucis radius, cum ad nos de origine sua, id est de Sole, pervenit, naturam secum ignis de quo nascitur devehit; cum vero in lunæ corpus infunditur et inde resplendet, solam refundit claritatem, non calorem." (So also Macrob. Saturnal. lib. vii. cap. 16, ed. Bip. T. ii. p. 277.)

(566) p. 354.—Mädler, Astr. § 112.

(567) p. 355.—See Lambert, "sur la Lumière cendrée de la Lune," in the Mém. de l'Acad. de Berlin, Année 1773, p. 46: "la Terre, vue des planètes, pourra paroitre d'une lumière verdâtre, à peu près comme Mars nous paroit d'une couleur rougeâtre." We do not mean by this to agree so far with that ingenious writer as to surmise that the planet Mars is covered with a red vegetation like the rose-coloured bushes of the Bougainvillæa. (Humboldt Ansichten der Natur, Bd. ii. S. 334; Engl. ed. "Aspects of Nature in Different Lands and Different Climates," Vol. ii. p. 279.) "In middle Europe, when the Moon, a short time *before* new moon, stands in the morning hours in the eastern sky, it receives the Earth-light principally from the great plateaus and plains of Asia and Africa: but when, *after* the time of new moon, it stands in the evening in the western sky, it can only receive the fainter reflection coming from the narrower American continent, and principally from the wide expanse of ocean." (Wilhelm Beer und Mädler, der Mond nach seinen kosmischen Verhältnissen, § 106, S. 152.)

(568) p. 355. — Séance de l'Académie des Sciences le 5 août 1833: "Mr. Arago signale la comparaison de l'intensité lumineuse de la portion de la Lune que les rayons solaires éclairent directement, avec celle de la partie du même astre qui reçoit seulement les rayons réfléchis par la Terre. Il croit d'après les expériences qu'il a dejà tentées à cet égard, qu'on pourra, avec des instrumens perfectionnés, saisir dans la *lumière cendrée* les différences de l'éclat plus ou moins nuageux de l'atmosphère de notre globe. Il n'est donc pas impossible, malgré tout ce qu'un pareil résultat exciterait de surprise au premier coup d'œil, qu'un jour les méteorologistes aillent puiser dans l'aspect de la Lune des notions précieuses sur *l'état moyen* de diaphanité de l'atmosphère terrestre, dans les hemisphères qui successivement concourent à la production de la lumière cendrée."

(569) p. 355.—Venturi, Essai sur les Ouvrages de Léonard de Vinci, 1797 p. 11.

(570) p. 355.—Kepler, Paralip. vel Astronomiæ pars Optica, 1604, p. 297.

(571) p. 356.—" On conçoit que la vivacité de la lumière rouge ne dépend pas uniquement de l'état de l'atmosphère, qui refracte, plus ou moins affaiblis, les rayons solaires, en les infléchissant dans le cône d'ombre, mais qu'elle est modifiée surtout par la transparence variable de la partie de l'atmosphère à travers laquelle nous apercevons la Lune éclipsée. Sous les tropiques une grand sérénité du ciel, une dissémination uniforme des vapeurs, diminuent l'extinction de la lumière que le disque lunaire nous renvoie." (Humboldt, Voyage aux Régions équinoxiales, T. iii. p. 544; and Recueil d'Observ. astronomiques, Vol. ii. p. 145.) Arago remarks: " Les rayons solaires arrivent à notre satellite par l'effet d'une réfraction et à la suite d'une absorption dans les couches les plus basses de l'atmosphère terrestre; pourroient-ils avoir une autre teinte que le rouge?" (Annuaire pour 1842, p. 528.)

(572) p. 356.—Babinet explains the redness as a consequence of diffraction, in a notice on the different portions of white, blue, and red light, produced when there is inflexion. See Babinet's considerations on the total eclipse of the Moon on the 19th of March, 1848, in Moigno's Répertoire d'Optique moderne, 1850, T. iv. p. 1656. "La lumière diffractée qui pénètre dans l'ombre de la terre, prédomine toujours et même a été seule sensible. Elle est d'autant plus rouge ou orangée qu'elle se trouve plus près du centre de l'ombre géométrique; car ce sont les rayons les moins réfrangibles qui se propagent le plus abondamment par diffraction, à mesure qu'on s'éloigne de la propagation en ligne droite." The phænomena of diffraction take place in vacuo also, according to the ingenious investigations of Magnus, on the occasion of a discussion between Airy and Faraday. On explanations by diffraction, see, generally, Arago in the Annuaire pour 1846, p. 452—455.

(573) p. 357.—Plutarch (de facie in orbe Lunæ), Moral. ed Wyttenb. T. iv. p. 780—783: " The fiery coal-glowing (ἀνθρακυειδης) colour of the darkened Moon (about the hour of midnight) is, as mathematicians maintain, by no means to be regarded, seeing that the change is from black to red and blueish, as belonging to the earthy surface of that body." Dion Cassius, also (lx. 26; ed Sturz, T. iii. p. 779),—who had besides occupied himself in much detail with the subject of lunar eclipses, and with the remarkable edicts of the Emperor Claudius, in which the dimensions of the darkened portion were announced beforehand,—calls attention to the great alterations in the colour of the Moon during the conjunction. He says (lxv. 11; T. iv. p. 185, Sturz): " Great was the confusion created in the camp of Vitellius by the eclipse which took place that night; yet it was not so much the eclipse itself—although to

minds already disturbed this might appear ominous of misfortune—as it was the circumstance of the Moon's varying colours—blood-red, black, and other mournful hues—which filled their souls with uneasy apprehensions."

([574]) p. 357.—Schröter, Selenotopographische Fragmente, Th. i. 1791, S. 668; Th. ii. 1802, S. 52.

([575]) p. 357.—Bessel, "über eine angenommene Atmosphäre des Mondes," in Schumacher's Astron. Nachr. No. 263, S. 416—420. Compare also Beer und Mädler, "der Mond," § 83 and 107, S. 133 and 153; as well as Arago, in the Annuaire for 1846, p. 346—353. The argument taken from the greater or less distinctness with which the smaller features of the Moon's surface can be recognised, so often adduced in proof of the reality of a lunar atmosphere, aud of "passing lunar mists in the valleys of the Moon," is the most untenable of all, seeing the changes continually taking place in the upper strata of our own atmosphere. Considerations respecting the shape of one of the Moon's horns in the solar eclipse of the 5th of September, 1793, led William Herschel to form even at that time a decided opinion *against* the hypothesis of a lunar atmosphere. (Phil. Trans. Vol. lxxxiv. p. 167.)

([576]) p. 358.—Mädler, in Schumacher's Jahrbuch für 1840, S. 188.

([577]) p. 358.—Sir John Herschel (Outlines, p. 247) calls attention to the immersion of double stars, which, from the great proximity of the individuals of which they consist, cannot be separated by the telescope.

([578]) p. 358.—Plateau, "sur l'Irradiation," in the Mém. de l'Acad. royale des Sciences et Belles-Lettres de Bruxelles, T. xi. p. 142; and "Ergänzungsband (supplementary volume) zu Poggendorff's Annalen, 1842, S. 79—128, 193—232, and 405—443. "The phænomenon of irradiation is probably caused by the stimulus produced by light extending itself on the retina a little beyond the outline of the image."

([579]) p. 358.—Arago, in the Comptes rendus, T. viii. 1839, p. 713 and 883. "Les phénomènes d'irradiation signalés par Mr. Plateau sont regardés par Mr. Arago comme les effets des aberrations de réfrangibilité et de sphéricité de l'œil, combinés avec l'indistinction de la vision, conséquence des circonstances dans lesquelles les observateurs se sont placés. Des mesures exactes prises sur des disques noirs à fond blanc et des disques blancs à fond noir, qui étaient placés au Palais du Luxembourg, visibles à l'Observatoire, n'ont pas indiqué les effets de l'irradiation."

([580]) p. 359.—Plut. Moral. ed. Wyttenb. T. iv. p. 786—789. The shadow of Mount Athos, as has also been remarked by the traveller, Pierre Belon (Observations de Singularités trouvées en Grèce, Asie etc. 1554, livre i.

chap. 25) reached to the broken figure of a cow on the market-place of the town of Myrine in the island of Lemnos.

([581]) p. 359.—For evidence of the visibility of these four objects, see S. 241, 338, 191, and 290, in Beer and Mädler's "der Mond." It is scarcely necessary to tell my readers that all that relates to the topography of the Moon's surface is taken from the excellent work of these my two friends, of one of whom, Wilhelm Beer, we have to lament the too early loss. The study of lunar topography will be facilitated by the use of the fine map in a single sheet ("Uebersichtsblatt"), published by Mädler in 1837, three years after the publication of the larger map of the Moon consisting of four sheets.

([582]) p. 359.—Plut. de facie in orbe Lunæ, p. 726—729, Wyttenb. The passage is at the same time not without interest for ancient geography: see Humboldt, Examen critique de l'Hist. de la Géogr. T. i. p. 145. Respecting other opinions of the ancients, see Anaxagoras and Democritus, in Plut. de plac. Philos. ii. 25; Parmenides, in Stob. p. 419, 453, 516 and 563, ed. Heeren; Schneider, Eclogæ physicæ, Vol. i. 433—443. (According to a very remarkable passage of Plutarch, in the Life of Nicias, cap. 42, Anaxagoras himself, who termed "the mountainous Moon another Earth," made a drawing of the Moon's disk: compare also Origenes, Philosophumena, cap. 8, ed. Mülleri, 1851, p. 14.) I was once very much astonished to hear a very accomplished Persian, of Ispahan, who had certainly never read a Greek book, to whom I was shewing in Paris the spots on the Moon's face through a large telescope, propound the same hypothesis of reflection as that of Agesianax, referred to in the text, as prevalent in his own country. "It is ourselves that we see in the Moon," said the Persian, "that is the map of our Earth." One of the interlocutors in Plutarch's Conversation on the Moon would not have expressed himself otherwise. Human beings in the Moon, if we could imagine such to exist in the absence of air and water, would see the rotating Earth with her spots suspended like one of our "Mappe-mondes," or "Maps of the World," against a sky almost black in the day-time, occupying a space fourteen times larger than that which the full moon covers to our eyes, and always in the same place. The study of geography would, however, be somewhat impeded by our atmosphere with its continued variations dimming and confusing the outlines of the continents. Compare Mädler's Astr. S. 169; and Sir John Herschel's Outlines, § 436.

([583]) p. 361.—Beer und Mädler, S. 273.

([584]) p. 362.—Schumacher's Jahrb. für 1841, S. 270.

([585]) p. 363.—Mädler, Astr. S. 166.

(586) p. 363.—The highest summit of the Himalayas,—and, according to our present knowledge, the highest on the surface of the earth,—Kinchin-junga, is, according to Waugh's recent measurement, 4406 toises, or 28178 English feet high (1·16 German geographical mile; 4·64 English geogr. miles); while the highest summit among the lunar mountains is, according to Mädler, 3800 toises, or exactly one German geographical mile. The diameter of the Moon is 454, and that of the Earth 1718 German geographical miles, whence the ratios of the highest summits to the diameters are in the case of the Moon $\frac{1}{454}$, and in that of the Earth $\frac{1}{1481}$.

(587) p. 364.—See for the six elevations which exceed 3000 toises, Beer und Mädler, S. 99, 125, 234, 242, 330, and 331.

(588) p. 366.—Robert Hooke, Micrographia, 1667, Obs. lx. p. 242—246. "These seem to me to have been the effects of some motions within the body of the Moon, analogous to our earthquakes, by the eruption of which, as it has thrown up a brim or ridge round about, higher than the ambient surface of the Moon, so has it left a hole or depression in the middle, proportionably lower." Hooke says of his experiments with "boyling alabaster," that, "presently ceasing to boyl, the whole surface will appear all over covered with small pits, exactly shaped like these of the Moon.—The earthy part of the Moon has been undermined or heaved up by eruptions of vapours, and thrown into the same kind of figured holes as the powder of alabaster. It is not improbable, also, that there may be generated, within the body of the Moon, divers such kind of internal fires and heats as may produce exhalations."

(589) p. 366.—Kosmos, Bd. ii. S. 508, Anm. 43; Eng. ed. p. civ. Note 483.

(590) p. 366.—Beer und Mädler, S. 126. Ptolemy has a diameter of 96 English geographical miles, and Alphonso and Hipparchus 76 such miles.

(591) p. 367.—Arzachel and Hercules form exceptions: the first has a crater at the summit, and the second a lateral crater. These geologically important points deserve fresh examination with more perfect instruments. (Schröter, Selenotopographische Fragmente, Th. ii. tab. 44 and 68, fig. 23.) Of lava-streams forming accumulations in low depressions, nothing has yet been observed. The rays which proceed in three directions from Aristotle are chains of hills. (Beer und Mädler, S. 236.)

(592) p. 367.—Beer und Mädler, S. 151; Arago, in the Annuaire for 1842, p. 526. (Compare also Immanuel Kant, Schriften der physischen Geographie, 1839, S. 393—402). Recent more careful and full examination has given reason to believe that the observed temporary alterations on the Moon's surface (the appearance of new central mountains and craters in the Mare Crisium,

and in Hevelius and Cleomedes), are to be attributed to an illusion similar to that which occasioned the belief in volcanic eruptions visible to us in the Moon. See Schröter, Selenotopogr. Fragm. Th. i. S. 412—523; Th. ii. S. 268—272. The question, what are the smallest objects whose height and other dimensions can be measured in the present state of our instrumental means, is one to which it is difficult to give a general answer. We find in Dr. Robinson's account of Lord Rosse's magnificent reflector, that in it an extent of 80 to 90 yards can be recognised with great clearness. Mädler reckons that, in his observations, shadows of 3 seconds were still measurable, which, under certain suppositions respecting the situation of the mountain and the height of the Sun, would correspond to an elevation of 120 French (128 English) feet; but he notices at the same time that the shadow must have a convenient breadth in order to be appreciable, or even visible. The shadow of the Great Pyramid of Cheops would, according to the known dimensions of that monument, be scarcely one-ninth of a second in breadth, even at its widest part, and would therefore remain invisible (Mädler, in Schumacher's Jahrbuch for 1841, S. 264). Arago reminds his readers, that, with a magnifying power of 6000 (which, besides, could not be applied to the Moon with a proportionally successful result), the mountains of the Moon would appear of the size of Mont Blanc seen with the naked eye from the Lake of Geneva.

([593]) p. 367.—The "rills" are not numerous; they are at most 100 or 120 miles long; sometimes forked (Gassendi), rarely resembling veins (Triesnecker), always shining; do not run across the mountains; are peculiar to the flatter districts; do not become either broader or narrower, and have nothing marked about their extremities. Beer und Mädler, S. 131, 225, and 249.

([594]) p. 368.—See my description of the "Nocturnal Life of Animals in the Primeval Forests," in the Ansichten der Natur (3te Ausg.), Bd. i. S. 334; Aspects of Nature in Different Lands and Different Climates, Vol. i. p. 270. Laplace's speculations (I am unwilling to apply to them a different term) on the manner in which he supposes perpetual moonlight might have been ensured (Exposition du Système du Monde, 1824, p. 232), have been refuted in a memoir by Liouville, "Sur un cas particulier du problème des trois corps." "Quelques partisans des causes finales," said Laplace, "ont imaginé que la lune a été donnée à la terre pour l'éclairer pendant les nuits; dans ce cas, la nature n'aurait point atteint le but qu'elle se serait proposé, puisque nous sommes souvent privés à la fois de la lumière du soleil et de celle de la lune. Pour y parvenir il eût suffi de mettre à l'origine la lune en opposition

avec le soleil, dans le plan même de l'écliptique, à une distance égale à la centième partie de la distance de la terre au soleil, et de donner à la lune et à la terre des vitesses parallèles et proportionnelles à leurs distances à cet astre. Alors la lune, sans cesse en opposition au soleil, eût décrit autour de lui une ellipse semblable à celle de la terre; ces deux astres se seraient succédé l'un à l'autre sur l'horizon; et comme à cette distance la lune n'eût point été éclipsée, sa lumière aurait certainement remplacé celle du soleil." Liouville finds, in opposition to this—"que si la lune avait occupé à l'origine la position particulière que l'illustre auteur de la *Mécanique céleste* lui assigne, elle n'aurait pu s'y maintenir que pendant un tems très court."

([595]) p. 368.—On the transporting power of Tides, see Sir Henry De la Beche, Geological Manual, 1833, p. 111.

([596]) p. 368.—Arago, "Sur la question de savoir, si la lune exerce sur notre atmosphère une influence appréciable," in the Annuaire pour 1833, p. 157—206. The principal authorities are:—Scheibler (Untersuch. über Einfluss des Mondes auf die Veränderungen in unserer Atmosphäre, 1830, S. 20); Flaugergaes (twenty years' observations at Viviers); Bibl. universelle, Sciences et Arts, T. xl. 1829, p. 265—283; and in Kastner's Archiv f. die ges. Naturlehre, Bd. xvii. 1829, S. 32—50; and Eisenlohr, in Pogg. Ann. der Physik. Bd. xxxv. 1835, S. 141—160, and 309—329. Sir John Herschel considers it very probable that a very high temperature (much above the boiling point of water) prevails on the surface of the Moon, which is exposed for 14 days together to the uninterrupted and unmitigated influence of the Sun. The Moon must hence, when in opposition, or a few days afterwards, be in some small degree a source of heat to the Earth: this heat, proceeding from a body much below the temperature of ignition, cannot, however, reach the surface of the Earth itself, but is absorbed in the upper strata of our atmosphere, where it changes visible cloud into transparent vapour. The phænomenon of the rapid dispersion of clouds by the full Moon, when the cloudy canopy is not too dense, is regarded by Sir John Herschel as a "meteorological fact," which (he adds) "is further confirmed by Humboldt's own experience, and by the very general belief of Spanish mariners in the American tropical seas." See Report of the Fifteenth Meeting of the British Association for the Advancement of Science, 1846, Notices, p. 5; and Outlines of Astronomy, p. 261.

([597]) p. 369.—Beer und Mädler, Beiträge zur phys. Kenntniss des Sonnensystems, 1841, S. 113, aus Beobachtungen von 1830 und 1832; Mädler, Astronomie, 1849, S. 206. The first, and considerable, correction of the time of rotation found by Dominique Cassini (24 hours, 40 minutes), was the

result of laborious observations by William Herschel (between 1777 and 1781), which gave 24 hours, 39 minutes, 21·7 seconds. Kunowsky found, in 1821, 24 hours, 36 minutes, 40 seconds, which is very near to Mädler's result. Cassini's earliest observation of the rotation of a spot of Mars (Delambre, Hist. de l'Astr. moderne, T. ii. p. 694), appears to have been made soon after the year 1670; but in the very rare treatise (Kern, Diss. de Scintillatione Stellarum, Wittenb. 1686, § 8), I find Salvator Serra and Father Ægidius Franciscus de Cottignez, Astronomer of the Collegio Romano, named as the discoverers of the rotation of Mars and Jupiter.

([598]) p. 369.—Laplace, Expos. du Syst. du Monde, p. 36. Schröter's very imperfect measurements of the diameters of the planet gave the ellipticity of Mars as only $\frac{1}{80}$.

([599]) p. 370.—Beer und Mädler, Beiträge, S. 111.

([600]) p. 370.—Sir John Herschel, Outlines, § 510.

([601]) p. 370.—Beer und Mädler, Beiträge, S. 117—125.

([602]) p. 370.—Mädler, in Schumacher's Astr. Nachr. No. 192.

([603]) p. 371.—Kosmos, Bd. iii. S. 427—429; Engl. ed. p. 304—306. Compare also, for what has been said in the present volume respecting the chronology of the discoveries of the small planets, S. 426 and 460; Engl. ed. p. 303 and 338;—respecting the proportion of their magnitudes to that of meteoric asteroids or aerolites, S. 432; Engl. ed. p. 309;—and respecting Kepler's conjecture of the existence of a planet in the great planetary gap between Mars and Jupiter (a conjecture which yet was by no means the occasion of the discovery of the first discovered of the small planets, Ceres), S. 439—444, and Anm. 31—33, S. 483; Engl. ed. p. 317—322, and Notes 523—525, p. cxix.—cxx. The bitter censure which has been expressed against a highly esteemed philosopher,—"because at a time when he might indeed have known Piazzi's discovery for five months, but did not know it, he denied, not so much the probability, but rather only the necessity, of there being a planet situated between Mars and Jupiter,"—appears to me but little justified. Hegel, in his Dissertatio de Orbitis Planetarum, written in the spring and summer of 1801, discusses the ideas of the ancients respecting the distances of the planets; and in remarking the series of which Plato speaks in the Timæus (p. 35, Steph.): 1 . 2 . 3 . 4 . 9 . 8 . 27 . . . . (compare Kosmos, Bd. iii. S. 477, Anm. 21; Engl. ed. p. cxv. Note 513) says, he denies the possibility of a gap. He says merely, ' Quæ series *si verior naturæ ordo sit,* quam arithmetica progressio, inter quartum et quintum locum magnum esse spatium, neque ibi planetam desiderari apparet" (Hegel's Werke, Bd. xvi. 1834, S. 28; and

Hegel's "Leben von Rosenkranz," 1844, S. 154). Kant, in his Naturgeschichte des Himmels, 1755, merely deems that, in the formation of the planets, Jupiter, by its enormous force of attraction, occasioned the smallness of Mars. He mentions only once, and then in a very indefinite manner, "the members of the solar system which are far asunder, and between which the intermediate parts have not yet been discovered;—Glieder des Sonnensystems, die weit von einander abstehen, und zwischen denen man die Zwischentheile noch nicht entdeckt hat" (Immanuel Kant, Sämmtliche Werke, Th. vi. 1839, S. 87, 110, and 196).

(604) p. 372.—Respecting the influence of improved star maps on the discovery of the small planets, see Kosmos, Bd. iii. S. 155 and 156; Engl. ed. p. 98 and 99.

(605) p. 372.—D'Arrest über das System der kleinen Planeten zwischen Mars und Jupiter (D'Arrest on the System of the Small Planets between Mars and Jupiter), 1851, S. 8.

(606) p. 372.—Kosmos, Bd. iii. S. 428 and 456; Engl. ed. p. 305—306, and 333—334.

(607) p. 374.—Benjaimn Abthorp Gould (now at Cambridge, Massachusetts, U.S.), Untersuchungen über die gegenseitige Lage der Bahnen zwischen Mars und Jupiter (Investigations respecting the Positions, relative to each other, of the Orbits between Mars and Jupiter), 1848, S. 9—12.

(608) p. 374.—D'Arrest, work above cited, S. 30.

(609) p. 374.—Zach, Monatl. Corresp. Bd. vi. S. 88.

(610) p. 375.—Gauss, in the same, Bd. xxvi. S. 299.

(611) p. 375.—Mr. Daniel Kirkwood (of the Pottsville Academy) has thought it possible to undertake the hypothetical reconstruction of the original shattered planet from the surviving fragments, after the manner followed in regard to the remains of extinct animals. He assigns to the planet a diameter larger than Mars (more than 1080 German, 4320 English, geographical miles), and a rotation slower than that of any other planet, making the length of its day 57½ hours (Rep. of the British Assoc. 1850, p. xxxv.)

(612) p. 376.—Beer und Mädler, Beiträge zur phys. Kenntniss der himml. Körper, S. 104—106. Older and more uncertain observations of Hussey even gave $\frac{1}{24}$. Laplace (Syst. du Monde, p. 266) finds theoretically, with increasing density of the strata, between $\frac{1}{24}$ and $\frac{5}{48}$.

(613) p. 376.—Newton's immortal work, Philosophia Naturalis Principia Mathematica, was published in May 1687, and the Memoirs of the Paris Academy, containing the notice of Cassini's determination of the ellipticity

($\frac{1}{15}$), did not appear until 1691; so that Newton, who might certainly have known Richer's pendulum experiments at Cayenne from the Voyage printed in 1679, must have been informed of the figure of Jupiter by verbal communication, and by the correspondence by letter which was then carried on with so much activity. On this subject, and on Huygens' only apparently-early knowledge of Richer's pendulum observations, see Kosmos, Bd. i. S. 420, Anm. 99; Engl. ed. p. xlii. Note 129; and Bd. ii. S. 520, Anm. 2: Engl. ed. p. cxxv. Note 542.

(614) p. 376.—Airy, in the Mem. of the Royal Astron. Society, Vol. ix. p. 7; Vol. x. p. 43.

(615) p. 377.—Still in the year 1824. (Laplace, Expos. du Syst. du Monde, p. 207).

(616) p. 377.—Delambre, Hist. de l'Astr. moderne, T. ii. p. 754.

(617) p. 678.—"On sait qu'il existe au-dessus et au-dessous de l'équateur de Jupiter deux bandes moins brillantes que la surface générale. Si on les examine avec une lunette, elles paraissent moins distinctes à mesure qu'elles s'éloignent du centre, et même elles deviennent tout-à-fait invisibles près des bords de la planète. Toutes ces apparences s'expliquent en admettant l'existence d'une atmosphère de nuages interrompue aux environs de l'équateur par une zone diaphane, produite peut-être par les vents alisés. L'atmosphère de nuages réfléchissant plus de lumière que le corps solide de Jupiter, les parties de ce corps que l'on verra à travers la zone diaphane, auront moins d'éclat que le reste, et formeront les bandes obscures. A mesure qu'on s'éloignera du centre, le rayon visuel de l'observateur traversera des épaisseurs de plus en plus grandes de la zone diaphane, en sorte qu'à la lumière réfléchie par le corps solide de la planète s'ajoutera la lumière réfléchie par cette zone plus épaisse. Les bandes seront par cette raison moins obscures en s'éloignant du centre. Enfin aux bords mêmes la lumière réfléchie par la zone vue dans la plus grande épaisseur pourra faire disparaître la différence d'intensité qui existe entre les quantités de lumière réfléchie par la planète et par l'atmosphère de nuages; on cessera alors d'apercevoir les bandes qui n'existent qu'en vertu de cette différence. On observe dans les pays de montagnes quelque chose d'analogue: quand on se trouve près d'une forêt de sapins, elle parait noire; mais à mesure qu'on s'en éloigne, les couches d'atmosphère interposées deviennent de plus en plus épaisses et réfléchissent de la lumière. La différence de teinte entre la forêt et les objets voisins diminue de plus en plus; elle finit par se confondre avec eux, si l'on s'en éloigne d'une distance convenable." (From Arago's Discourses on Astronomy, 1841).

([618]) p. 379.—Kosmos, Bd. ii. S. 357—359 and 509, Anm. 44; Engl. ed. p. 316—318, and cxiv. Note 484.

([619]) p. 380.—Sir John Herschel, Outlines, § 540.

([620]) p. 381.—The earliest careful observations of William Herschel, in Nov. 1793, gave for the rotation of Saturn 10 hours, 16 minutes, 44 seconds. It has been erroneously stated, that, forty years before William Herschel, the great philosopher Kant, in his ingenious Allgemeine Naturgeschichte des Himmels, inferred truly the time of rotation of Saturn from theoretical considerations. The number which he assigned was 6 hours, 23 minutes, 53 seconds. He called his determination the "mathematical computation of an unknown movement of a heavenly body, which is perhaps the only prediction of its kind in natural science, and must await its confirmation from future observations." The hoped-for confirmation did not arrive; on the contrary, observation has shewn that the anticipation was in error 4 hours, or three-fifths of its amount. In the same work he says of Saturn's ring, that of the accumulated particles of which it consists, those of the interior margin perform their course in 10 hours, and those of the exterior margin in 15 hours. The first of these two numbers, applied to the ring, is the only one which is, accidentally, near to the observed time of rotation of the planet. Compare Kant, Sämmtliche Werke, Th. vi. 1839, S. 135 and 140.

([621]) p. 381.—Laplace (Expos. du Syst. du Monde, p. 43) estimates the compression at the poles at $\frac{1}{11}$. The singular supposed deviation of Saturn from a spheroidal figure, in conformity with which William Herschel, by a series of elaborate observations, made, moreover, with very different telescopes, found the major axis of the planet, not in the equator itself, but in a diameter crossing the equatorial diameter at an angle of about 45°, has not been confirmed by Bessel, but, on the contrary, was believed by him to have been erroneous.

([622]) p. 382.—Arago, Annuaire pour 1842, p. 555.

([623]) p. 382.—This difference of the intensity of light of the inner and the outer ring was already noticed by Dominique Cassini (Mém de l'Académie des Sciences, Année 1715, p. 13).

([624]) p. 382.—Kosmos, Bd. ii. S. 359; Engl. ed. p. 318—319. The *publication* of the discovery, or rather of the complete explanation of all the phænomena presented by Saturn and his ring, was not made until four years later, in 1659, in the Systema Saturnium.

([625]) p. 384.—Such mountain-like inequalities have recently been noticed by

Lassell, at Liverpool, with a twenty-foot reflector made by himself (Rep. of the British Association, 1850, p. xxxv.)

([626]) p. 384.—Compare Harding's Kleine Ephemeriden für 1835, S. 100; and Struve, in Schum. Astr. Nachrichten, No. 139 S. 389.

([627]) p. 384.—We read in the Actis Eruditorum pro anno 1684, p. 424, as an extract from the "Systema phænomenorum Saturni, autore Galletio, proposito eccl. Avenionensis:" — "Nonnunquam corpus Saturni *non exacte annuli medium* obtinere visum fuit. Hinc evenit, ut, quum planeta orientalis est, centrum ejus extremitati orientali annuli proprius videatur, et major pars ab occidentali latere sit cum ampliore obscuritate."

([628]) p. 385.—Horner, in Gehler's Neuem physik. Wörterbuch (New Physical Dictionary), Bd. viii. 1836, S. 174.

([629]) p. 385.—Benjamin Peirce on the Constitution of Saturn's ring, in Gould's Astron. Journal, 1851, Vol. ii. p. 16. "The ring consists of a stream, or of streams, of a fluid rather denser than water flowing around the primary." Compare also Silliman's Amer. Journal, 2d series, Vol. xii. 1851, p. 99; and respecting the inequalities of the ring, and the perturbing, and thereby maintaining, influences of the satellites, John Herschel, Outlines, p. 320.

([630]) p. 386.—Sir John Herschel, Results of Astron. Observ. at the Cape of Good Hope, p. 414—430; the same, in the Outlines of Astr. p. 650; and upon the Law of the Distances, § 550.

([631]) p. 387.—Fries, Vorlesungen über die Sternkunde, 1833, S. 325; Challis, in the Transact. of the Cambridge Philos. Society, Vol. iii. p. 171.

([632]) p. 387.—William Herschel, Account of a Comet, in the Phil. Trans. for 1781, Vol. lxxi. p 492.

([633]) p. 388.—Kosmos, Bd. iii. S. 445; Engl. edit. p. 323.

([634]) p. 388.—Mädler, in Schumacher's Astr. Nachr. No. 493. (Compare, respecting the ellipticity or compression at the poles of Uranus, Arago, Annuaire for 1842, p. 577—579.)

([635]) p. 390.—For the observations of Lassell, at Starfield (Liverpool), and of Otto Struve, compare Monthly Notices of the Royal Astron. Soc. Vol. viii. 1848, p. 43—47, and 135—139; also Schum. Astr. Nachr. No. 623, S. 365.

([636]) p. 390.—Bernhard von Lindenau, Beitrag zur Gesch. der Neptun's-Entdeckung (Contribution to the History of the Discovery of Neptune), im Ergänz. Heft zu Schum. Astr. Nachr. 1849, S. 17.

([637]) p. 391.—Astr. Nachr. No. 580.

(638) p. 391.—Le Verrier, Recherches sur les Mouvemens de la Planète Herschel, 1846, in the Connaissance des Temps pour l'an 1849, p. 254.

(639) p. 391.—The very important element of the mass of Neptune has gradually increased from $\frac{1}{20897}$ according to Adams, $\frac{1}{19840}$ according to Peirce, $\frac{1}{19400}$ according to Bond, and $\frac{1}{18780}$ according to John Herschel; to $\frac{1}{15480}$ according to Lassell, and $\frac{1}{14446}$ according to Otto and August Struve. The last-named Pulkowa result has been adopted in the text.

(640) p. 392.—Airy, in the Monthly Notices of the Royal Astr. Soc. Vol. vii. No. 9 (Nov. 1846), p. 121—152; Bernhard von Lindenau, Beitrag. zur Gesch. der Neptun's-Entdeckung, S. 1—32 and 235—238. Le Verrier, at the instance of Arago, began in the summer of 1845, to work at the theory of Uranus. He laid the results of his investigation before the Institute on the 10th of Nov. 1845, the 1st of June, 31st of August, and 5th of Oct. 1846, and published them at once; but his greatest and most important work, which contained the solution of the whole problem, only appeared in the Connaissance des Temps pour l'an 1849. Adams, without printing anything, laid the first results which he had obtained for the perturbing planet before Professor Challis, in September 1845, and the same, with some modification, in the following month, Oct. 1845, before the Astronomer-Royal,—still without publishing anything. The Astronomer-Royal received from Adams his final results, with some fresh corrections relating to a diminution of the distance, in the beginning of September 1846. The young Cambridge geometrician has expressed himself with noble modesty and self-denial on the subject of this chronological succession of labours, which were all directed to the same great object:—"I mention these earlier dates merely to shew that my results were arrived at independently, and previously to the publication of M. Le Verrier, and not with the intention of interfering with his just claims to the honours of the discovery; for there is no doubt that his researches were first published to the world, and led to the actual discovery of the planet by Dr. Galle: so that the facts stated above cannot detract in the slightest degree from the credit due to M. Le Verrier." As in the history of the discovery of Neptune mention has often been made of the early participation of the great astronomer of Königsberg in the expectation already expressed in 1834 by Alexis Bouvard (the author of the Tables of Uranus), that the perturbations of Uranus might be caused by a planet still unknown to us, I think it may perhaps be agreeable to some of my readers that I should publish here a portion of a letter written to me by Bessel, under date 8th May, 1840,—two years, therefore, before his conver-

sation with Sir John Herschel, during his visit to Collingwood. "You wish for tidings respecting the planet beyond Uranus. I might refer you to friends at Königsberg who, from a misunderstanding, think they know more about it than I do myself. I had chosen for a public lecture (on the 28th of Feb. 1840), the subject of the connection between astronomical observations and astronomy. The public knows of no difference between the two, and it was desirable to give them juster views in this respect. In shewing the development of astronomical knowledge from observations, I was naturally led to remark that we cannot yet by any means assert that our theory explains all the motions of the planets. Uranus was adduced in proof of this, as the old observations of that planet do not suit at all with the elements which can be inferred from the later observations made from 1783 to 1820. I think I once before told you that I had worked much at this question, but that I had not arrived at more than the *certainty* that the existing theory, or rather its application to the solar system, *so far as it is known* to us, does not suffice to solve the enigma presented by Uranus. I do not, however, believe that we ought on this account to regard it as not susceptible of solution. We must first know accurately and completely all that has been observed respecting Uranus. I have got one of my young auditors, Fleming, to reduce and compare all the observations, and thus I now have all the existing data before me. If the old observations do not suit well with the theory, the later ones do so still less; for the error is again already a full minute, and it increases annually by seven or eight seconds, so that it will soon be considerably larger. I have thence thought that a time would come in which the solution of the enigma might perhaps be found in a new planet, whose elements might be recognised from its effects on Uranus, and confirmed by those on Saturn. I was far from saying that this time had actually arrived, but I mean now to try *how far* the existing facts may lead. This is a work which I have had by me so many years, and I have already pursued so many different views for its sake, that its completion has peculiar attractions for me, and I shall, therefore, omit nothing to bring it about as soon as possible. I have great confidence in Fleming, who at Dantzig, whither he is now called, will prosecute for Jupiter and Saturn the same reduction of observations as that which he has now performed for Uranus. It is, in my estimation, a fortunate circumstance that he has, for the present, no means of making observations, and that he is not engaged in any lectures. No doubt a time will arrive for him also when he will have to make observations *for a definite object;* and then he will, I trust, be as far from wanting the requisite means as he is now from wanting the skill."

(641) p. 393.—The first letter in which Lassell announced the discovery was dated the 6th of August, 1847. (Schumacher's Astr. Nach. No. 611, S. 165).

(642) p. 393.—Otto Struve, in the Astr. Nachr. No. 629. August Struve, at Dorpat, computed the orbit of the first satellite of Neptune from the observations at Pulkowa.

(643) p. 393.—W. C. Bond, in the Proceedings of the American Academy of Arts and Sciences, Vol. ii. p. 137 and 140.

(644) p. 393.—Schum. Astr. Nachr. No. 729, S. 143.

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(645) p. 395.—Kant says: "The last planets beyond Saturn will be found to bear an increasing resemblance to comets, until one class of bodies is connected with or passes by gradual transition into the other. This supposition is supported by the law according to which the excentricity of the planetary orbits increases with their distance from the Sun. The remoter planets approach thereby nearer to the definition of comets. The last planet, and first comet, may be the body which at its perihelion shall be found to intersect the orbit of the next planet, perhaps Saturn. Our theory of the mechanical formation of the heavenly bodies is also clearly proved (!) by the magnitude of the planetary masses increasing with their distance from the Sun." Kant, Naturgesch. des Himmels (1755) in his Sämmtl. Werken, Th. vi. S. 88 and 195. In the beginning of the 5th Part (S. 131) he had spoken of the "earlier comet-like nature which Saturn had laid aside."

(646) p. 396.—Stephen Alexander "on the Similarity of Arrangements of the Asteroids and the Comets of Short Periods, and the Possibility of their Common Origin," in Gould's Astron. Journal, No. 19, p. 147, and No. 20, p. 181. The author distinguishes, with Hind (Schum. Astr. Nachr. No. 724) "the comets of short period, whose semi-axes are all nearly the same with those of the small planets between Mars and Jupiter; and the other class, including the comets, whose mean distance or semi-axis is somewhat less than that of Uranus." He concludes the first memoir with the statement that "different facts and coincidences agree in indicating a near appulse, if not an actual collision, of Mars with a large comet in 1315 or 1316; that the comet was thereby broken into three parts, whose orbits (it may be presumed) received even then their present form, viz. that still presented by the comets of 1812, 1815, and 1846, which are fragments of the dissevered comet."

(647) p. 397.—Laplace, Expos. du Syst. du Monde (éd. 1824), p. 414.

([648]) p. 397.—On comets, see Kosmos, Bd. i. S. 105—120, and 389—393, Anm. 12—27; Engl. ed. p. 91—105, and p. xvii.—xx. Notes 42—57.

([649]) p. 398.—In seven half-centuries, from 1500 to 1850, there have appeared in all 52 comets visible to the naked eye in Europe, or taking each interval of half a century separately and successively, respectively—13, 10, 2, 10, 4, 4, and 9. Taking them thus in half-centuries, and giving the year of the appearance of each comet, we have:—

1500—1550
13 comets.

1550—1600
10 comets.

1600—1650
1607
1618
——
2 comets.

1650—1700
1652
1664
1665
1668
1672
1680
1682
1686
1689
1696
——
10 comets.

1700—1750
1702
1744
1748 (2)
——
4 comets.

1750—1800
1759
1766
1769
1781
——
4 comets.

1800—1850
1807
1811
1819
1823
1830
1835
1843
1845
1847
——
9 Comets.

Of the 23 comets stated above to have been visible to the naked eye in Europe in the 16th century (the age of Apianus, Girolamo Fracastoro, the Landgrave William the IVth of Hesse, Mästlin, and Tycho Brahe), ten have

been described by Pingré, viz. those of 1500, 1505, 1506, 1512, 1514, 1516, 1518, 1521, 1522, and 1530; as well as the comets of 1531, 1532, 1533, 1556, 1558, 1569, 1577, 1580, 1582, 1585, 1590, 1593, and 1596.

(650) p. 399.—This is the "malignant comet" which was supposed to announce (or occasion), in storm and shipwreck, the death of the celebrated Portuguese discoverer, Bartholomew Diaz, when he sailed wi h Cabral from Brazil to the Cape of Good Hope. Humboldt, Examen crit. de l'Hist. de la Géogr. T. i. p. 296, and T. v. p. 80 (Sousa, Asia Portug. T. i. P. i. cap. 5, p. 45).

(651) p. 399.—Laugier, in the Connaissance des Temps pour l'an 1846, p. 99. Compare also Edouard Biot, Recherches sur les Anciennes Apparitions Chinoises de la Comète de Halley antérieures à l'Annee 1378, work before cited, p. 70—84.

(652) p. 399.—On the comet discovered by Galle in March 1840, see Schumacher's Astr. Nachr. Bd. 17, S. 188.

(653) p. 399.—See my Vues des Cordillères (éd. in-folio), Pl. lv. fig. 8, p. 281—282. The Mexicans had also a very correct view of the cause of a solar eclipse. The same Mexican manuscript, executed at least a quarter of a century before the arrival of the Spaniards, represents the Sun as almost covered by the disk of the Moon, and shews the stars visible at the same time.

(654) p. 400.—This origin of the *tail* from the *front* part of the head of the comet which engaged so much of Bessel's attention, is in accordance with the view already taken by Newton and by Winthrop. (Compare Newton, Princip. p. 511; and Phil. Trans. Vol. lvii. for the year 1767, p. 140, fig. 5.) Newton thought that the tail was developed in greatest strength and length when near to the Sun, because the celestial air (that which with Encke we call the "resisting medium") is there most dense, and the "particulæ candæ," being strongly heated, ascend most easily, being upborne by the denser celestial air. Winthrop thought that the principal effect does not take place until a little after the perihelion, because, according to the law established by Newton (Princip. p. 424 and 466), maxima are always in arrear (as in periodical changes of temperature, as well as in the tides of the sea).

(655) p. 400.—Arago, in the Annuaire for 1844, p. 395. The observation was made by the younger Amici.

(656) p. 400.—On the comet of 1843, which in the month of March of that year shone out with a lustre unexampled in the North of Europe, and which approached nearer to the Sun than any other observed and calculated comet, see Sir John Herschel's Outlines of Astronomy, § 589—597; and Peirce,

American Almanac for 1844, p. 42. External or physiognomic resemblances, the uncertainty of which had, however, been pointed out so long ago as by Seneca in his Nat. Quæst. lib. vii. cap. 11 and 17, had at first given occasion to this comet being supposed to be identical with those of 1668 and 1689. (Kosmos, Bd. i. S. 144 and 410, Anm. 62; Engl. ed. p. 129 and xxxiii. Note 92: and Galle, in "Olbers Cometenbahnen," No. 42 and 50.) Boguslawski (Schum. Astr. Nachr. No. 545, S. 272) believed, on the other hand, that the earlier appearances of this comet, assigning to it a period of revolution of 147 years, had been those of 1695, 1548, and 1401: he even calls it "the comet of Aristotle," because he traces it back to 371 B.C., and, with the talented Hellenist, Thiersch, of Munich, considers it to be the comet mentioned in the Meteorol. of Aristotle, Book i. cap. 6. I would remark, however, that the name "Comet of Aristotle" is liable to much uncertainty in respect to its signification. If the comet which Aristotle makes to have disappeared in the constellation of Orion, and which he connects with the earthquake in Achaia, be meant, it must not be forgotten that this comet is stated by Calisthenes to have appeared *before*, by Diodorus *after*, and by Aristotle *at the time of*, the earthquake. The 6th and 8th chapters of Aristotle's Meteorology treat of four comets, the epochs of whose appearance are indicated by references to the Archons at Athens, and to different calamitous events. He there mentions successively the "western" comet, which appeared at the time of the great earthquake in Achaia, with which great inundations were connected (cap. 6, 8); then the comet which appeared in the time of the Archon Eucles, the son of Molon (cap. 6, 10); and subsequently the Stagirite speaks again of the western comet, that of the great earthquake, and names in connection with it the Archon Asteus, a name which incorrect readings have converted into Aristæus, and who, on that account, Pingré, in his Cométographie, erroneously regards as the same person as Aristhenes or Alcisthenes. The lustre of this comet of Asteus extended over a third part of the heavens: its tail, therefore, which was called "the way" (ὁδός), was 60° in length. It stretched to the neighbourhood of Orion, where it was dissolved. In cap. 7, 9, mention is made of the comet which appeared simultaneously with the celebrated fall of a meteoric stone at Ægos Potamoi (Kosmos, Bd. i. S. 124, 397, and 407; Engl. ed. p. 109, xxiii. and xxxi. Note 87), and which cannot well be a mere confusion with the aerolite-cloud described by Damachos as having shone and sent forth shooting stars during a period of 70 days. Lastly, Aristotle names, in cap. 7, 10, a comet which was seen under the Archon Nicomachus, and to which a tempest at Corinth was ascribed. These

four appearances of comets fall in the long period of 32 Olympiads, viz. the comet contemporaneous with the aerolitic fall, according to the Parian chronicle, Ol. 78, 1 (468 B.C.), under the Archon Theagenides; the great comet of Asteus, which appeared at the time of the earthquake in Achaia, and disappeared in the constellation of Orion, in Ol. 101, 4 (373 B.C.); the comet of Eucles, the son of Molon, erroneously called Euclides by Diodorus (xii. 53), in Ol. 88, 2 (427 B.C.), as is also confirmed by the Commentary of Johannes Philoponos; and the comet of Nicomachus, in Ol. 109, 4 (341 B.C.) In Pliny, ii. 25, the 108th Olympiad is assigned to the jubæ effigies mutata in hastam. Seneca also agrees in the immediate connection of the comet of Asteus (Ol. 101, 4) with the earthquake in Achaia, inasmuch as he mentions in the following manner the destruction of Bura and Helice, which towns are not expressly named by Aristotle: "Effigiem ignis longi fuisse, Callisthenes tradit, antequam Burin et Helicen mare absconderet. Aristoteles ait, non trabem illam, sed cometam fuisse." (Seneca, Nat. Quæst. vii. 5.) Strabo (viii. p. 384, Cas.) places the destruction of these two often mentioned cities two years before the battle of Leuctra, whence we should again have the date Ol. 101, 4. Lastly, when Diodorus Siculus has described the same event in more detail as taking place under the Archon Asteus (xv. 48 and 49), he places the bright "shadow-casting" comet (xv. 50) under the Archon Alcisthenes, a year later, Ol. 102, 1 (372 B.C.), and makes it a herald of the downfall of the Lacedæmonian dominion; but Diodorus had the habit of transferring an event from one year to another, and the more ancient and secure authorities, Aristotle and the Parian Chronicle, testify in favour of the epoch of Asteus in preference to that of Alcisthenes. Now as, by the assumption of a period of revolution of 147¾ years for the fine comet of 1843, Boguslawski traces it through 1695, 1548, 1401, and 1106, back to 371 years before our era, we find it agree with the comet of the earthquake in Achaia, according to Aristotle within two, and according to Diodorus even within one, year, which, if we could know anything of the similarity of the orbits, would, indeed, be a very small error considering the probable perturbations in so long an interval. If Pingré, in his Cométographie, 1783, T. i. p. 259—262 (on the authority of Diodorus, and taking Alcisthenes instead of Asteus as the name of the Archon), places the appearance of the comet in Orion of which we are speaking in Ol. 102, and yet calls the date July 371 instead of 372 B.C., it is no doubt because he agrees with some astronomers in marking the first year before the Christian Era as anno 0. It must be remarked, in conclusion, that Sir John Herschel takes for the bright comet of 1843 quite

a different period of revolution, viz. 175 years, which would trace it back to the years 1668, 1493, and 1318. (Compare Outlines of Astronomy, p. 370 to p. 372, with Galle, in Olbers Cometenbahnen, S. 208, and Kosmos, Bd. i S. 144, Engl. ed. p. 93.) Other combinations of Peirce and Clausen even give periods of revolution of $21\frac{4}{5}$ or $7\frac{1}{5}$,—years,—sufficient proof of how hazardous it is to trace back the comet of 1843 to the time of the Archon Asteus. The mention in the Meteorol. lib. i. cap. 7, 10, of a comet under the Archon Nicomachus, has the advantage of informing us that Aristotle was at least 44 years old when that work was written. It has always surprised me that this great man, who must have been already 14 years old at the time of the earthquake of Achaia, and of the appearance of the great comet in Orion with a tail of 60° in length, should have spoken with so little animation of so brilliant an object, contenting himself with merely enumerating it as one of the comets "that had been seen in his time." The surprise is increased on finding it said in the same chapter that he had seen with his own eyes something nebulous, or even a faint appearance of a mane (κόμη), round a fixed star in the "thighbone of the Dog" (perhaps Procyon in Canis minor), Meteorol. i. 6, 9. Aristotle also speaks (i. 6, 11) of his observation of the occultation of a star in Gemini by the disk of Jupiter. What is said of a nebulous mane or vaporous envelope of Procyon (?), reminds me of a phænomenon repeatedly spoken of in the ancient Mexican imperial annals, according to the Codex Tellerianus. "This year" (it is said) "Citlalcholoa" (the planet Venus, also called in Aztec Tlazoteotl, see my Vues des Cordillères, T. ii. p. 303) "was again seen to smoke." The appearances seen respectively in the Greek and Mexican sky were probably small halos round the star and the planet, the phænomenon being one of atmospheric refraction.

(657) p. 400.—Edouard Biot, in the Comptes rendus, t. xvi. 1843, p. 751.

(658) p. 401.—Galle, in the appendix to "Olbers Cometenbahnen," S. 221, No. 130. (On the probable passage of the two-tailed comet of 1823, see Edinb. Rev. 1848, No. 175, p. 193.) The memoir referred to in the text, containing the true elements of the comet of 1680, does away with Halley's fanciful idea, according to which that comet, having a supposed period of revolution of 575 years, would have appeared at certain great epochs in the history of mankind: at the time of the Flood according to the Hebrews, at the time of Oxyges according to the Greeks, the Trojan War, the destruction of Nineveh, the death of Julius Cæsar, &c. Encke's calculation gives the comet's period 8814 years. Its least distance from the surface of the Sun, on the 17th Dec. 1680, was only 32000 German, or 128000 English, geogra-

phical miles; being 80000 English geographical miles less than the distance of the Moon from the Earth. The aphelion of the comet is 853·3 distances of the Earth from the Sun, and the ratio of its least to its greatest distance from the Sun is as 1 : 140000.

(659) p. 401.—Arago, in the Annuaire pour 1832, p. 236—255.

(660) p. 402.—Sir John Herschel, Outlines, § 592.

(661) p. 402.—Bernhard von Lindenau, in Schum. Astr. Nachr. No. 698, S. 25.

(662) p. 402.—Kosmos, Bd. iii. S. 46—49; Engl. ed. p. 36—39.

(663) p. 403.—Le Verrier, in the Comptes rendus, t. xix. 1844, p. 982—993.

(664) p. 404.—Newton assumed that the brightest comets possess only a light reflected from the Sun. Splendent cometæ luce Solis a se reflexa. (Princ. mathem. ed. Le Seur et Jacquier, 1760, T. iii. p. 577.)

(665) p. 404.—Bessell, in Schumacher's Jahrbuch für 1837, S. 169.

(666) p. 404.—Kosmos, Bd. i. S. 113, and Bd. iii. S. 50; Engl. ed. Vol. i. p. 99, and Vol. iii. p. 40.

(667) p. 405.—Valz, Essai sur la Détermination de la Densité de l'Etner dans l'Espace planétaire, 1830, p. 2; and Kosmos, Bd. i. S. 112; Engl. ed. Vol. i. p. 98. Hevelius, who was always so careful and unprejudiced an observer, had already had his attention drawn to the enlargement of the nuclei of comets with increasing distance from the Sun (Pingré, Cométographie, T. ii. p. 193). Determinations of the diameter of Encke's comet when near the Sun are very difficult, if exactness is aimed at. The comet is a nebulous mass, in which the middle, or a part of the middle, is strikingly the brightest. From this place, which has not at all the appearance of a disk, and cannot be called a comet's head, the light decreases rapidly on all sides. At the same time the nebulosity is prolonged in one direction, so that this prolongation appears like a tail. Measurements of the comet's dimensions refer, therefore, to this nebulosity, the circumference of which, without having any very well-defined outline, diminishes when the comet is at its perihelion.

(668) p. 405.—Sir John Herschel, Results of Astron. Observ. at the Cape of Good Hope, 1847, § 366, Pl. xv. and xvi.

(669) p. 406.—Although still later (5th of March) the distance between the two comets was seen to increase to 9° 19′, yet this increase, as Plantamour has shewn, was only apparent, being dependent on increased approximation to the Earth. From February to the 10th of March, the two portions of the double comet continued to be at an equal distance from each other.

(670) p. 406.—Le 19 février 1846, on aperçoit le fond noir du ciel qui

sépare les deux comètes. (Otto Struve, in the Bulletin physico-mathématique de l'Acad. des Sciences de St.-Pétersbourg, T. vi. No. 4.)

([671]) p. 406.—Compare "Outlines of Astronomy," § 580—583; Galle, in Olbers Cometenbahnen, S. 232.

([672]) p. 407.—"Ephorus non religiosissimæ fidei, sæpe decipitur, sæpe decipit. Sicut hic cometem, qui omnium mortalium oculis custoditus est, quia ingentis rei traxit eventus, cum Helicen et Burin ortu suo merserit, ait illum discessisse in duas stellas: quod præter illum nemo tradidit. Quis enim posset observare illud momentum quo cometes solutus et in duas partes redactus est? Quomodo autem, si est qui viderit cometem in duas derimi, nemo vidit fieri ex duabus?" (Seneca, Nat. Quæst. lib. vii. cap. 16.)

([673]) p. 407.—Edouard Biot, Recherches sur les Comètes de la Collection de Ma-tuan-lin, in the Comptes rendus, T. xx. 1845, p. 334.

([674]) p. 408.—Galle, in "Olbers Methode der Cometenbahnen," S. 232, No. 174. The comets of Colla and Bremiker, of the years 1845 and 1840, combine elliptic orbits with not very long periods of revolution (not long, I mean, if compared with the periods of 3065 and 8800 years of the comets of 1811 and 1680). The comets of Colla and Bremiker appear to have periods of only 249 and 344 years. (See Galle, in the last-quoted work, S. 229 and 231.)

([675]) p. 409.—The short period of revolution of 1204 days was recognised by Encke on the reappearance of his comet in 1819. See the first calculated elliptic orbits in the Berlin "Astron. Jahrbuch" for 1822, S. 193; and for the constants of "the resisting medium" assumed for the explanation of the accelerated revolution, see Encke's "Vierte Abhandl." in the "Schriften der Berliner Akademie" for 1844. (Compare Arago, in the Annuaire pour 1832, p. 181, in the "Lettre à Mr. Alexandre de Humboldt," 1840, p. 12; and Galle, in Olbers Cometenbahnen, S. 221.) In reference to the history of Encke's comet, it remains to be noticed that, so far as our knowledge of observations extends, it was first seen, 17 Jan. 1786, by Mechain, on two days; then by Miss Caroline Herschel, 7—27 Nov. 1795; then by Bouvard, Pons, and Huth, Oct. 20—Nov. 19, 1805; and lastly—this being its tenth return since its discovery by Mechain in 1786—from the 26th of November, 1818, to the 12th of January, 1819, by Pons. The first return *calculated beforehand* by Encke was observed by Rümker at Paramatta (Galle, Olbers Methode der Cometenbahnen, S. 215, 217, 221, and 222).—Biela's, or, as it is also called, Gambart and Biela's interior comet, was first seen on the 8th of March, 1772, by Montaigne; then by Pons on the 10th of November, 1805; then on the 27th of February, 1826, at Josephstadt, in Bohemia, by Herr von

Biela; and on the 9th of March, 1826, at Marseilles, by Gambart. Undoubtedly the earlier rediscoverer of the comet of 1772 was Biela, and not Gambart; but, on the other hand, the latter determined the elliptic elements earlier than Biela, and almost simultaneously with Clausen. (Arago, in the Annuaire pour 1832, p. 184, and in the Comptes Rendus, T. iii. 1836, p. 415.) The first precalculated return of Biela's comet was observed in October and December 1832 by Henderson, at the Cape of Good Hope. The extraordinary bipartition of Biela's comet took place, on its eleventh reappearance since 1772, at the end of the year 1845. See Galle, in Olbers, S. 214, 218, 224, 227, and 232.

(676) p. 409.—Outlines, § 601.

(677) p. 411.—Laplace, Expos. du Système du Monde, p. 396 and 414. Laplace's particular view respecting comets as wandering nebulæ (petites nébuleuses errantes de systèmes en systèmes solaires) is opposed in many ways by the advances which, since the death of that great astronomer, have been made in regard to the resolvability into crowded clusters of stars of so many nebulæ; and also by the circumstance that comets are found to have a portion of reflected polarised light, which, in self-luminous cosmical bodies, is entirely wanting. (Compare Kosmos, Bd. iii. S. 180, 320, 329, 357, Anm. 25 and 26, and S. 362, Anm. 46; Engl. edit. p. 122, 225, 234, lxxx. and lxxxi. Notes 382 and 383, and lxxxv. Note 403.

(678) p. 412.—At Babylon, in the learned Chaldæan school of astrologers, as well as with the Pythagoreans and generally in the ancient schools, there was a division of opinion. Seneca (Nat. Quæst. vii. 3) adduces the opposite statements of Apollonius Myndius and Epigenes. The latter is a writer seldom named, yet Pliny (vii. 57) terms him "gravis auctor in primis," and he is also mentioned, though without praise, in Censorinus de die natali, cap. 17, and Stob. Ecl. phys. i. 29, p. 586, ed. Heeren. (Compare Lobeck, Aglaoph. p. 341.) Diodorus (xv. 50) thought that the general and prevailing opinion of the Babylonian astrologers (Chaldæans) was, that comets return at fixed times in determinate paths. The division of opinion which prevailed among the Pythagoreans respecting the planetary nature of comets, and which is indicated by Aristotle (Meteorol. lib. i. cap. 6, 1) and Pseudo-Plutarch (De plac. Philos. lib. iii. cap. 2), also extended, according to the former (Meteorol. i. 8, 2), to the opinions formed concerning the nature of the Milky Way,—the abandoned path of the Sun, from which Phaeton was precipitated. (Compare Letronne, in the Mém. de l'Acad. des Inscriptions, 1839, T. xii. p. 108.) The opinion of *some* among the Pythagoreans quoted by Aristotle was, that

"comets belong to the number of those planets which, like Mercury, are a long time before they can become visible by ascending above the horizon in their course." In the very fragmentary Pseudo-Plutarch it is said that comets "rise at fixed periods after having completed their course." Many things respecting the nature of comets contained in scattered writings of Arrian, of whom Stobæus might have made use, and of Charimander, whose name alone has been preserved by Seneca and Pappus, have been lost to us. Stobæus cites as the opinion of the Chaldæans (Eclog. lib. i. cap. 25, p. 61, Christ. Plantinus), "that comets are so rarely visible because in their long course they hide themselves far away from us in the depths of æther (or of space), like fishes in the depths of the ocean." The most pleasing, and, notwithstanding the rhetorical colouring of the passage, the soundest remarks, and most consonant with our present opinions on the subject of comets, which we meet with among ancient writers, are by Seneca. We read in Nat. Quæst. lib. vii. cap. 22, 25, and 31 : "Non enim existimo cometem subitaneum ignem, sed inter æterna opera naturæ.—Quid enim miramur, cometas, tam rarum mundi spectaculum, nondum teneri legibus certis? nec initia illorum finesque patescere, quorum ex ingentibus intervallis recursus est? Nondum sunt anni quingenti, ex quo Græci......stellis numeros et nomina fecit. Multæque hodie sunt gentes, quæ tantum facie noverint cælum, quæ nondum sciant, cur luna deficiat, quare obumbretur. Hoc apud nos quoque nuper ratio ad certum perduxit. Veniet tempus, quo ista, quæ nunc latent, in lucem dies extrahat et longioris ævi diligentia.—Veniet tempus, quo posteri nostri tam aperta nos nescisse mirentur.—Eleusis servat, quod ostendat revisentibus. Rerum natura sacra sua non simul tradit. Initiatos nos credimus; in vestibulo ejus hæremus. Illa arcana non promiscue nec omnibus patent, reducta et in interiore clausa sunt. Ex quibus aliud hæc ætas, aliud quæ post nos subibit, despiciet. Tarde magna proveniunt."

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([679]) p. 421.—The spectacle of the starry heavens presents to our view objects not contemporaneous: much has long since disappeared, even before it became visible to our eyes, and in much the order and arrangement have changed. (Kosmos, Bd. i. S. 161 and 416; Bd. iii. S. 90 and 125: Engl. edit. Vol. i. p. 145 and xxxix.; Vol. iii. p. 72 and xxx. Compare Bacon, Nov. Organ. Lond. 1733, p. 371; and William Herschel, in the Phil. Trans. for 1802, p. 498.)

(680) p. 421.—Kosmos, Bd. i. S. 137, 142, and 407, Anm. 55; Engl. ed. p. 122, 126—127, and xxxii. Note 90.

(681) p. 422.—See the opinions of the Greeks on the fall of meteoric stones, in Kosmos, Bd. i. S. 138, 139, 395, 397, 401, 402, 407, Anm. 31, 32, 39, 57—59; Bd. ii. S. 501, Anm. 27: Engl. ed. Vol. i. p. 123, 124, xxi. xxii. xxiii. xxvii. and xxxi.—xxxii. Notes 61, 62, 69, and 87—89; Vol. ii. p. cvii. Note 467.

(682) p. 422.—Brandis, Gesch. der Griechisch-Röm. Philosophie, Th. i. S. 272—277, against Schleiermacher, in the Abhandl. der Berl. Akad. aus den J. 1804—1811 (Berl. 1815), S. 79—124.

(683) p. 423.—If Stobæus in the same passage (Ecl. phys. p. 508) makes Diogenes of Apollonia call the stars "bodies of a substance resembling pumice-stone" (porous stones, therefore), this description may have been favoured by the very prevalent idea in antiquity, that all celestial bodies were fed by humid exhalations. The Sun "gives back that which he has sucked up" (Aristot. Meteorol. ed. Ideler, T. i. p. 509; Seneca, Nat. Quæst. iv. 2). The "pumice-like bodies" seen as shooting stars were also supposed to have their own exhalations. "These bodies, which cannot be seen so long as they wander about in space, are stones which kindle and then become extinguished, when they fall to the earth" (Plat. de plac. Philos. ii. 13). Pliny (ii. 59) believed that many meteoric stones fall—"decidere tamen crebro, non erit dubium:" he also knew that their fall, while the air is clear, is accompanied by a loud noise (ii. 43). The seemingly analogous passage of Seneca, in which he names Anaximenes (Nat. Quæst. lib. ii. 17), refers probably to the thunder from a storm-cloud.

(684) p. 423.—The remarkable passage in Plut. Lys. cap. 12, translated closely, is as follows:—"It is a probable opinion which was held by those who said that, shooting stars are not emanations or overflowings from the æthereal fire, which become extinguished in the air immediately after being kindled; neither are they produced by ignition and combustion of a quantity of air which has detached itself towards the higher regions; but rather they are heavenly bodies which fall or are cast down in consequence of an intermission, or irregularity, of the force of rotation, and are precipitated not only on inhabited countries, but also, and in greater numbers, beyond these, into the great sea, so that they remain concealed."

(685) p. 423.—On absolute dark bodies, or bodies in which the luminous process ceases (periodically?); on the opinions of modern authorities (Laplace and Bessel); and on Bessel's observation, confirmed by Peters at Königs-

berg, of an alteration in the proper motion of Procyon,—see Kosmos, Bd. iii. S. 267—269; Engl. edit. p. 182 and 183.

(686) p. 424.—Compare Kosmos, Bd. iii. S. 42—44, and 54, Anm. 17; Engl. edit. p, 33—35, and x. Note 63.

(687) p. 424.—The remarkable passage alluded to in the text (Plutarch, de facie in orbe Lunæ, p. 923), closely translated, is as follows:—"Yet the Moon is kept from (or helped against) falling, by its own motion, and by the impetuosity of its revolution, as things placed in slings are hindered from falling by being whirled round in a circle."

(688) p. 426.—Kosmos, Bd. i. S. 126; Engl. edit. p. 112.

(689) p. 426.—Coulvier-Gravier and Saigey, Recherches sur les Etoiles filantes, 1847, p. 69—86.

(690) p. 426.—"Die periodischen Sternschnuppen und die Resultate der Erscheinungen, abgeleitet aus den wahrend der letzten 10 Jahre zu Aachen angestellten Beobachtungen, von Eduard Heis" (On Periodical Shooting Stars, and the Results derived from Observations of these Phænomena, made during the last Ten Years at Aix-la-Chapelle, by Edward Heis), 1849, S. 7 and 26—30.

(691) p. 426.—The assignment of the North Pole as a centre of radiation or point of departure of shooting stars in the August period, rests only on the observations of a single year, 1839 (10th of August). A traveller in the East, Dr. Asahel Grant, writes from Mardin, in Mesopotamia, that about midnight the sky was as it were furrowed by shooting stars, which all proceeded from the vicinity of the North Pole (Heis, S. 28, according to a letter from Herrick to Quetelet, and according to Dr. Grant's journals).

(692) p. 427.—This superiority of the point of departure in Perseus over that in Leo in respect to the number of shooting stars, was, however, far from shewing itself in the Bremer observations of the night 13 to 14 Nov. 1838. In a very rich fall of shooting stars, a very practised observer, Roswinkel, saw almost all the paths take their departure from the constellation of Leo and the southern part of Ursa Major; while, on the night of the 12th to the 13th of November, when the number of shooting stars was but little inferior, only four of their paths proceeded from Leo. Olbers (Schum. Astr. Nachr. No. 372) adds, very significantly: "The paths on this night shewed nothing of parallelism, and no reference to the constellation of Leo; and, on account of this absence of parallelism, they would appear to belong to the class of sporadic, not to that of periodic, shooting stars. The November phænomenon of this year could not indeed be compared in brilliancy to those of the years 1799, 1832, and 1833."

(693) p. 428.—Saigey, p. 151; and on Erman's determination of the points of "convergence," diametrically opposite to the points of radiation or departure, Saigey, p. 125—129.

(694) p. 428.—Heis, Period. Sternschn. S. 6. (Compare Aristot. Problem. xxvi. 23; Seneca, Nat. Quæst. lib. i. 14: "ventum significat stellarum discurrentium lapsus, et quidem ab ea parte qua erumpit.") I myself long believed (and particularly while I was staying at Marseilles, at the time of the French expedition to Egypt) in the influence of wind on the direction of shooting stars.

(695) p. 429.—Kosmos, Bd. i. S. 395; Engl. edit. p. xxi.

(696) p. 429.—I am indebted for all the part of the text to which marks of quotation are appended, to the kind communications of Herr Julius Schmidt, Adjunct to the Astronomical Observatory at Bonn. On his earlier investigations, from 1842 to 1844, see Saigey, p. 159.

(697) p. 431.—Yet I saw myself, in the Pacific ($13\frac{1}{2}°$ N. lat.), a considerable fall of shooting stars on the 16th of March, 1803. Two streams of meteors were also seen in the month of March, in China, 687 years before our era. (Kosmos, Bd. i. S. 133; Engl. edit. p. 118.)

(698) p. 433.—A fall of shooting stars quite similar to that of 1836, October 21, Old Style, of which the younger Boguslawski found the account in Benesse de Horovic Chronicon Ecclesiæ Pragensis (Kosmos, Bd. i. S. 133; Engl. ed. p. 118), is described in a discursive manner in the celebrated historical work of Duarte Nunez do Lião (Chronicas dos Reis de Portugal reformadas, Parte i. Lisb. 1600, fol. 187), but is there transferred to the night from the 22d to the 23d of October. Were two streams seen on different nights in Bohemia and on the Tagus, or may we not rather suppose that one of the two chroniclers was in error by a day? The following are the words of the Portuguese historian:—"Vindo o anno de 1366 sendo andados xxii dias do mes de Octubro, tres meses antes do fallecimento del Rei D. Pedro (de Portugal), so fez no ceo hum movimento de estrellas, qual os homẽes não virão nem ouvirão. E foi que desda mea noite por diante correrão todalas strellas do Levante para o Ponente, e acabado de serem juntas começarão a correr humas para huma parte e outras para outra. E despois descerão do ceo tantas e tam spessas, que tanto que forão baxas no ar, parecião grandes fogueiras, e que o ceo e o ar ardião, e que a mesma terra queria arder. O ceo parecia partido em muito spaço. Os que isto vião, houverão tam grande medo e pavor, que stavão como attonitos, e cuidavão todos de ser mortos, e que era vinda a fim do mundo."

(699) p. 433.—Still closer coincidences in point of time might have been

cited if they had been known; for example, the streams of meteors observed by Klöden, at Potsdam, 1823, 12—13 Nov.; by Bérard, on the Spanish coast, 1831, 12—13 Nov.; and by Count Suchteln, at Orenburg, 1832, Nov. 12—13. (Kosmos, Bd. i. S. 129, Engl. edit. p. 114; and Schumacher's Astr. Nachr. No. 303, S. 242.) The great phænomenon of the 11th and 12th November, 1799, described by Bonpland and myself (Voyage aux Régions équinoxiales, livre iv. chap. 10, T. iv. p. 34—53, éd. in-8vo.), lasted from 2 h. to 4 h. A.M. Throughout our entire journey through the forest region of the Orinoco, and as far south as the Rio Negro, we found that this extraordinary fall of meteors had been seen by the missionaries, and in some cases had been noted in their ecclesiastical records. It had also been seen and had astonished the Esquimaux in Labrador and in Greenland, as far as Lichtenau and New Herrnhut, in latitude 64° 14′. This phænomenon, which was visible in America at the same time at the equator and near the polar circle, was also seen in Europe by the Minister Zeising, at Itterstedt, near Weimar. The periodicity of the stream of St. Lawrence (10th of August) did not draw general attention until much later than the November phænomenon. I have collected with care all the accounts with which I am acquainted, of accurately observed and considerable falls of meteors of the 12th to the 13th of November, up to 1846. I find fifteen such falls:—in 1799, 1818, 1822, 1823, 1831, 1832, 1833, 1834, 1835, 1836, 1837, 1838, 1839, 1841, and 1846. All which differ more than a day or two—as Nov. 10, 1787, and Nov. 8, 1813—are excluded. This degree of periodicity, almost to a single day, is the more surprising, because bodies of such small mass are so easily liable to perturbation, and the breadth of the ring in which the meteors are imagined to be included may comprise several days of the Earth's course in its orbit. The most brilliant November streams have been those of 1799, 1831, 1833, and 1834. [Where, in my description of the meteors of 1799, it is said that a ball of fire had a diameter of 1° or 1½°, it should have been—1 or 1¼ diameters of the Moon.] This is the place for mentioning also the ball of fire which attracted the special attention of Monsieur Petit, Director of the Astronomical Observatory of Toulouse, and of which he has computed the revolution round the Earth. (Comptes rendus, 9 Août 1847; and Schum. Astr. Nachr. No. 701, S. 71.)

(700) p. 437.—Forster, Mémoire sur les Etoiles filantes, p. 31.

(701) p. 438.—Kosmos, Bd. i. S. 131 and 405; Engl. ed. p. 116 and xxix.

(702) p. 438.—Kämtz, Lehrbuch der Meteorologie, Bd. iii. S. 277.

(703) p. 439.—The great fall of aerolites of Crema and the banks of the

Adda has been described with great liveliness, but unfortunately in too rhetorical a manner, and with a great want of clearness, by the celebrated Petrus Martyr, of Anghiera (Opus Epistolarum, Amst. 1670, No. cccclxv. pag. 245—246). The fall of stones was immediately preceded by an almost total obscuration of the Sun at noon, on the 4th of September, 1511. "Fama est, Pavonem immensum in aërea Cremensi plaga fuisse visum. Pavo visus in pyramidem converti, adeoque celeri ab occidente in orientem raptari cursu, ut in horæ momento magnam hemisphæri partem, doctorum inspectantium sententia, pervolasse credatur. Ex nubium illico densitate tenebras ferunt surrexisse, quales viventium nullus unquam se cognovisse fateatur. Per eam noctis faciem, cum formidolosis fulguribus, inaudita tonitrua regionem circumsepserunt." The temporary illuminations were so intense as to enable the inhabitants round Bergamo to see the whole plain of Crema during the darkness which otherwise prevailed. "Ex horrendo illo fragore quid irata natura in eam regionem pepererit, percunctaberis. Saxa demisit in Cremensi planitie (ubi nullus unquam æquans ovum lapis visus fuit) immensæ magnitudinis, ponderis egregii. Decem fuisse reperta centrilibralia saxa ferunt." Birds, sheep, and even fish, were killed. Among all these exaggerations, we can still recognise that the meteoric cloud from which the stones fell must have been of uncommon blackness and density. The "Pavo" was doubtless a ball of fire with a train or tail both wide and long. The tremendous noise issuing from the meteoric cloud is here described as the thunder accompanying the lightnings (?). Anghiera received himself, in Spain, a fragment the size of a man's fist (ex frustis disruptorum saxorum), and shewed it to the King, Ferdinand of Arragon, in the presence of the celebrated warrior, Gonzalo de Cordova. His letter concludes with the words "mira super hisce prodigiis conscripta fanatice, physice, theologice ad nos missa sunt ex Italia. Quid portendant, quomodoque gignantur, tibi utraque servo, si aliquando ad nos veneris" (written from Burgos to Fagiardus). Cardanus, speaking still more precisely (Opera, ed. Lugd. 1663, T. iii. lib. xv. cap. 72, p. 279), states that there fell 1200 aerolites, and that among them was one weighing 120 pounds, very dense, and of a blackness like that of iron. He also says that the noise lasted two hours: "ut mirum sit, tantam molem in aëre sustineri potuisse." He takes the ball of fire with a tail or train for a comet, and makes the mistake of a year in the date of the phænomenon: "Vidimus anno 1510......" Cardanus was between nine and ten years old when it occurred.

([704]) p. 439.—Recently, in the fall of aerolites at Braunau (July 14, 1847), the masses of stone which fell were, six hours afterwards, still so hot that

they could not be touched without burning the hand. I have already treated, in my Asie centrale (T. i. p. 408), of the analogy presented by the Scythian myth of "the sacred gold" to a fall of meteors. "Targitao filios fuisse tres, Leipoxain et Arpoxaiu, minimumque natu Colaxain. His regnantibus de cœlo delapsa aurea instrumenta, aratrum et jugum et bipennem et phialam, decidisse in Scythicam terram. Et illorum natu maximum, qui primus conspexisset, propius accedentem capere ista voluisse; sed, eo accedente aurum arsisse. Quo digresso, accessisse alterum, et itidem arsisse aurum. Hos igitur ardens aurum repudiasse; accedente vero natu minimo, fuisse exstinctum, huncque illud domum suam contulisse: qua re intellecta, fratres majores ultro universum regnum minimo natu tradidisse" (Herodot. iv. 5 and 7, according to the version of Schweighauser). But perhaps the myth of the sacred gold may be only an ethnographical myth, containing an allusion to three king's sons, ancestors or founders of three tribes of Scythians (?), and to the pre-eminence attained by the tribe of the youngest son, or that of the Paralati (?) (Brandstäter, Scythica, de aurea caterva, 1837, p. 69 and 81).

(705) p. 441.—Of metals, there have been discovered in meteoric stones,—nickel by Howard, cobalt by Stromeyer, copper and chrome by Laugier, and tin by Berzelius.

(706) p. 442.—Rammelsberg, in Poggendorff's Annalen, Bd. lxxiv. 1849, S. 442.

(707) p. 445.—Shepard in Silliman's American Journal of Science and Arts, 2d series, Vol. ii. 1846, p. 377; Rammelsberg, in Poggend. Ann. Bd. lxxiii. 1848, S. 585.

(708) p. 445.—Compare Kosmos, Bd. i. S. 135; Engl. edit. p. 120.

(709) p. 446.—Zeitschrift der deutschen geolog. Gesellschaft, Bd. i. S. 232. All those parts in the text, between p. 442 and p. 445, which are distinguished by marks of quotation, are taken from Professor Rammelsberg's manuscripts of May 1851.

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